BRITISH COLUMBIA

Ministry of Water, Land & Air Protection

LOWER MAINLAND REGION

Sea-to-Sky Airshed
Ambient Air Quality Monitoring
Report: 1984-2001

ENVIRONMENTAL QUALITY

Sea-to-Sky Airshed Ambient Air Quality Monitoring Report: 1984-2001

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Preface

This report is one in a series of water, groundwater, and air quality reports that are being issued by the Lower Mainland Regional Office in fiscal year 2004/05. It is the intention of the Regional Office to publish water, groundwater and air quality reports on our website (http://wlapwww.gov.bc.ca/sry/p2/eq/index.htm) in order to provide the information to industry and local government, other stakeholders and the public at large. By providing such information in a readily understood format, and on an ongoing basis, it is hoped that local environmental quality conditions can be better understood, and better decisions regarding water, groundwater and air quality management can be made.

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EXECUTIVE SUMMARY

This report summarizes the meteorological and air quality data collected by the Ministry of Water, Land and Air Protection (formerly Ministry of Environment and Ministry of Environment, Lands and Parks) in the Sea-to-Sky Airshed over the past two decades (from 1984 to 2001). This includes monitoring of criteria air contaminants (sulphur dioxide, total reduced sulphur, nitrogen dioxide, ozone and particulate matter) as well as meteorological data (wind speed and direction, and temperature). The intent of this report is to give a technical summary of data collected in the Sea-to-Sky Airshed since measurement began (there is presently no such summary available), and to give some interpretation of trends in the data where applicable. This report is not intended to provide detailed analysis of the causes or actions needed to manage the air quality in this Airshed. Work that is presently in progress (2004) will aim to provide more detailed airshed characterization, identify specific air quality concerns, and work towards the goal of developing an Air Quality Management Plan for the Airshed.

The Sea-to-Sky Airshed is located in the Lower Mainland Region of British Columbia, northwest of Vancouver, encompassing the area around Howe Sound, north through Squamish, Whistler and Pemberton. It is bounded on the southern end at 49° 20' N and on the northern end at 50° 25' N. The eastern and western boundaries follow the Howe Sound, Green River, and Cheakamus River valleys, bounded roughly by 123° 35' W and 122° 40' W longitude.

Non-continuous monitoring of dust (particulate matter) and sulphur began in the corridor in 1971, but due largely to changes in monitoring technology, the historic data has limited value for comparison and trend analysis with continuous data collected since the 1980s. For the years 1984 to 2001, air quality monitoring was conducted for varying periods at 18 different stations in the Sea-to-Sky Airshed, and meteorological monitoring was conducted at 4 locations. Two of the permanent monitoring stations are in place as part of an agreement between pulp mill permit holders and the province (Squamish and Langdale). The remaining stations (continuous and non-continuous) are in place as reference stations to ensure that air quality objectives and/or air quality management targets are being met.

Summary of Monitoring Results 1984-2001

The Ministry has been monitoring air quality in the Sea-to-Sky Corridor since 1971, although changes in monitoring technology have rendered the pre-1984 data of limited use for comparative and trend analysis purposes. In general, the Sea-to-Sky airshed is quite clean, although particulate matter and ozone can occasionally exceed national and provincial air quality objectives in the summer. As well, odour events usually associated with the pulp mills in the region occur less than 10 hours (not necessarily continuous) in a given year. Monitoring of the following pollutants has been conducted since the mid-1980s: sulphur dioxide (SO_2), total reduced sulphur (TRS), nitrogen dioxide (NO_2), ground-level ozone (O_3), inhalable particulate matter (PM_{10}), fine particulate matter ($PM_{2.5}$), and total suspended particulate (TSP).

Sulphur Dioxide (SO_2) – Mean SO_2 levels in the Sea to Sky Airshed are measured in Squamish and Langdale (and were measured briefly in Gibsons), and have been monitored continuously since the mid-1990s. These concentrations are low, with annual averages lower than 3 $\mu g/m^3$ (the annual BC Level A objective is 25 $\mu g/m^3$). Since monitoring began in the 1990s, there have been zero exceedances of the strictest air quality objectives for any averaging period. There is a notable correlation at both monitoring stations between winds blowing from the direction of the pulp mills and slightly elevated SO_2 concentrations. Hourly SO_2 concentrations that are 'driven' by emissions from the pulp and paper industry tend to be episodic in nature, relating to fluctuations in industrial activity. It is therefore difficult to discern any temporal trends in the SO_2 data. The highest 1-hour SO_2 concentration ever recorded since measurement began was 72 $\mu g/m^3$ (in 1999) in Squamish, and 61 $\mu g/m^3$ (in 1997) in Langdale. The 1-hour BC Level A (most stringent) objective for SO_2 is 450 $\mu g/m^3$.

Total Reduced Sulphur (TRS) – While the mean levels of TRS in the Sea-to-Sky Airshed are low, there have been exceedances (between 1 to 22 hours per year in the last decade) of the 1-hour BC Level A Objective for TRS (7 $\mu g/m^3$) in the Lower Sea-to-Sky/Howe Sound region. Due to differences in monitoring instrumentation and detection limits over time, trend analysis and inter-decadal comparison is problematic. In general there appear to be less exceedances of the 1-hour BC Level A Objective in the period since 1995 compared with the 1980s. This is consistent with changes to TRS pollution control

technology at nearby pulp mills. For the permanent TRS monitoring stations, Langdale experiences higher maximum concentrations and more frequent exceedances of the Level A Objective than does Squamish. However, annual averages (< 1 $\mu g/m^3$) and 98th percentile concentrations (< 3 $\mu g/m^3$) are quite similar for both sites. There is a significant correlation between winds blowing from the pulp mills toward the monitoring stations and higher TRS concentrations.

Nitrogen Dioxide (NO_2) – NO_2 has historically been measured in Langdale since 1995 and all measurements to date have been well below all national air quality objectives for all averaging periods (1-hour maximum since measurement began is 109 $\mu g/m^3$, compared with the national Maximum Acceptable Objective of 400 $\mu g/m^3$). A possible increasing trend in the annual average NO_2 concentrations has, however, been observed since the mid-1990s (from an annual average of 6 $\mu g/m^3$ to 10 $\mu g/m^3$), although adequate data is missing for the years 1998 and 1999. This difference may be due to increasing population and associated vehicle emissions in the western Howe Sound region, as no new point sources have been established in the region. However, further analysis is required to confirm this potential trend.

Ozone (O_3) – Ozone is currently measured in Squamish and Whistler, and was measured for a brief period in Pemberton during the mid-1980s. The 1-hour national Maximum Desirable Objective of 100 $\mu g/m^3$ is exceeded every summer in Squamish (for 36 hours per year on average), and the 1-hour maximum acceptable objective of 160 $\mu g/m^3$ was exceeded on two days in the summer of 1998. The highest 1-hour concentration ever recorded at Squamish was 172 $\mu g/m^3$. The summer-time maximums are due to meteorological conditions typical of summer in the region when a mass of stable air is stagnant and prevents pollutants from dispersing. In Whistler, ozone measurements only began in April 2001, but data from the summer of 2001 indicates that 1-hour ozone maximum concentrations are nearly as high as those in Squamish. Measurements of ozone from 1986 in Pemberton indicate that levels in the Sea-to-Sky corridor are not significantly lower than those measured for the same period in the Lower Fraser Valley, although the daytime maximums are not always as high. An ozone characterization study in the Sea-to-Sky Airshed was conducted in the summer of 2003 and may help determine the major contributors to ozone formation in this airshed, be they locally produced, advected, or due to elevation differences.

Inhalable Particulate Matter (PM_{10}) – Particulate Matter under 10 microns (PM_{10}) data is collected by both continuous and non-continuous monitors in the Sea-to-Sky Airshed. Continuous monitoring has been conducted in Squamish and Langdale since the mid-1990s, while non-continuous monitoring has been conducted at varying times in Squamish, Langdale, Horseshoe Bay, Whistler, and Gibsons in the past two decades. The highest recorded 24-hour PM_{10} concentration from continuous monitoring occurred in Squamish in the summer of 1998 (62 $\mu g/m^3$), while the highest recorded 24-hour PM_{10} concentration from a non-continuous monitor also occurred in Squamish, in the spring of 1992 (78 $\mu g/m^3$). The BC Level B 24-hour PM_{10} air quality objective is 50 $\mu g/m^3$, while the Health Reference Level is 25 $\mu g/m^3$. The Health Reference Level is exceeded 54 days per year on average in Squamish, while the BC Level B objective is exceeded 0.8 days per year. These exceedances usually occur in summer, although occasionally are associated with winter outflow winds from the interior of the province or with localized open burning.

Fine Particulate Matter ($PM_{2.5}$) – Fine Particulate Matter under 2.5 microns ($PM_{2.5}$) is collected using a non-continuous sampling system in Squamish. It was installed in February 2001. The highest reading in that year for a 24-hour period was 19 $\mu g/m^3$. While data is insufficient to compare with the newly established Canada Wide Standards for $PM_{2.5}$, it can be compared against a 24-hour Health Reference Level of 15 $\mu g/m^3$. This Reference Level was exceeded on 1 occasion in 2001.

Total Suspended Particulate (TSP) – TSP was measured historically from 1971 to 1992 in the Sea to Sky Airshed, but is no longer being measured. From 1985 to 1992, it was measured using non-continuous monitors in Squamish, Langdale and Horseshoe Bay. The highest recorded 24-hour TSP concentration during that period was 172 $\mu g/m^3$ in the winter of 1985 in Squamish (the BC Level A Objective for 24 hours is 150 $\mu g/m^3$), although the annual geometric mean for the region ranges from ~25 to 50 $\mu g/m^3$ (the BC Level A Annual Objective is 60 $\mu g/m^3$). Therefore dust concentrations in the airshed were, with the exception of one measurement, below the most stringent national and provincial standards for TSP since 1985.

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1.0 INTRODUCTION

This report summarizes the meteorological and air quality data collected in the Sea-to-Sky Airshed since modern, standardized measurements began in the region (1984-2001). While there is some additional historical non-continuous data for particulates, mercury and other air contaminants in the region dating as far back as the 1970s, this data is not directly comparable to the data presented in this report, or to current air quality objectives and standards. (This data will, however, be made available on a free data CD). The details can be found on the Ministry of Water, Land and Air Protection Lower Mainland Region website: (http://wlapwww.gov.bc.ca/sry/p2/eq/index.htm).

The Sea-to-Sky (STS) Airshed includes the areas surrounding Howe Sound in Southwestern British Columbia, and follows the "Sea-to-Sky Corridor" north to Pemberton, as outlined in Figure 1.1. The Sea to Sky Airshed was divided into two regions for the purposes of an emissions inventory published in 2002. These two regions are named the Lower and Upper STS airsheds (LSTS and USTS). The purpose of this division was to highlight the fact that the main industrial sources (including the two pulp mills) are located in the Lower section, whereas the Upper section represents sources that are more closely related to tourism and residential activities. This results in different proportions of emissions from each source category, and provides an easier method of targeting emission sources for air quality management purposes.

The LSTS airshed includes Gibsons, Langdale, Horseshoe Bay, and the municipality of Squamish. The USTS airshed includes the Resort Municipality of Whistler and the Village of Pemberton. Both sections were delimited using topographical information as it is assumed that the air travels within a certain corridor defined by the elevated landscape on either side of the Sea-to-Sky corridor, as shown in Figure 1.1. However, it is important to note that a number of adjoining valleys were not included in the Airshed, although they may contribute unknown quantities of air contaminants via transport from the Lower Fraser Valley or surrounding regions.

The STS Airshed also includes a small portion of the Greater Vancouver Regional District (GVRD) airshed. The section of the STS Airshed which is included in the GVRD is of a rectangular shape and is bordered by longitudes 123°25' and 123°12' W and by latitudes 49°30' and 49°20' N. It includes a portion of West Vancouver as well as Bowen Island and Lions Bay. The resulting STS Airshed boundary is shown in Figure 1.1.

There have been no previous summary reports on the ambient air quality data in the Sea-to-Sky Airshed, although there were special study reports done for Whistler (*PM_{10} in 1994-1995, and PM_{10} and Ozone 1997-2001*). It is therefore the goal of this report to adequately summarize the available data, and where appropriate, look at the long term trends of some of the criteria air contaminants (sulphur dioxide, total reduced sulphur, nitrogen oxides, particulate matter, and ozone). In future years, summary reports will be published on an annual to bi-annual basis and will attempt to build on the findings of this report and to expand on the analysis and trends. The purpose of these reports will be to assess the trends in concentration of each of the criteria air contaminants, and to use this information to evaluate the effectiveness of air quality management planning (initiated in 2002) in the Sea-to-Sky Airshed.

The need for a summary air quality report for the Sea-to-Sky Airshed has arisen in recent years due to growing concerns about the air quality in this region. While historically the region has been dependent on resource industries, there is now a strong tourism and recreation-based sector throughout the corridor that places a high priority on pristine environmental quality. The forecast increase growth in motor vehicle emissions and in municipal growth for the Resort Municipality of Whistler and the Village of Pemberton, as well as the successful 2010 Olympic Games bid, are all additional factors and pressures being placed on the air quality in the region.

This report provides an overview assessment of the Sea-to-Sky Airshed data collected since 1984, outlining the monitoring network, the national and provincial air quality objectives, meteorological data, pollution data measured by both continuous and non-continuous monitors, and descriptions of monitoring stations.

Figure 1.1: Sea-to-Sky Airshed Boundaries Delineating the Upper and Lower STS Regions.

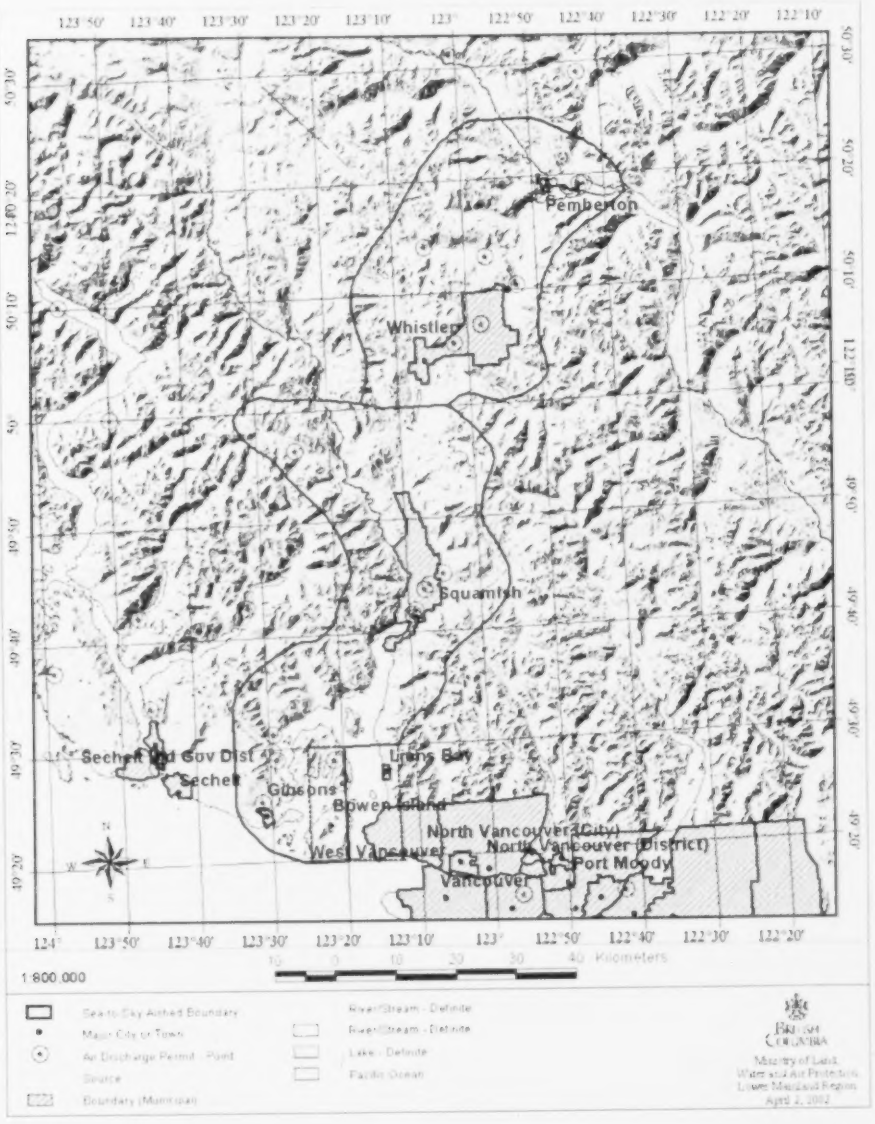
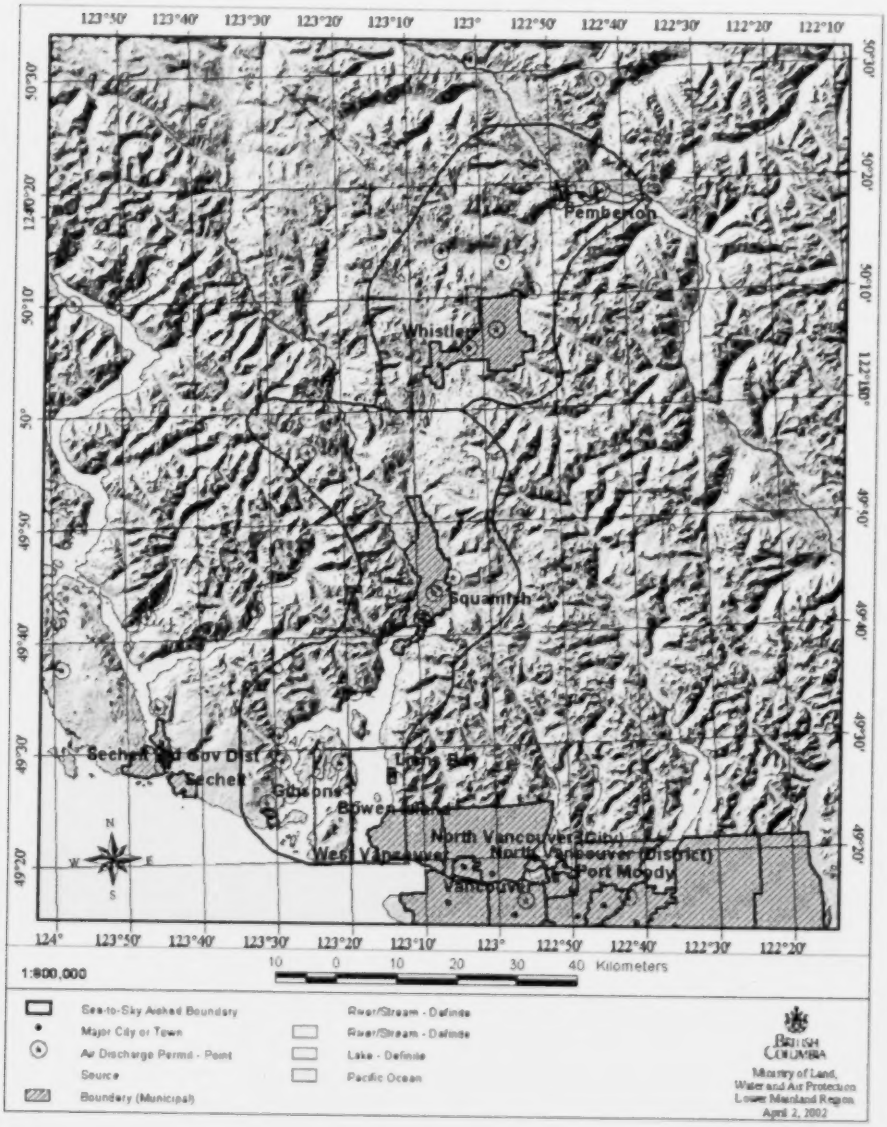


Figure 1.1: Sea-to-Sky Airshed Boundaries Delineating the Upper and Lower STS Regions.



2.0 MONITORING NETWORK

Air quality monitoring conducted by the Ministry of Water, Land and Air Protection (formerly Ministry of Environment and Ministry of Environment, Land and Parks) began in the Sea-to-Sky Airshed in 1971 in response to concerns regarding mercury emissions from a chlor-alkali plant in Squamish, and also as part of a provincial air program that began under the Pollution Control Act of 1967. Primarily total suspended particulate and dustfall, coefficient of haze (CoH), and sulfation plate measurements were taken as part of the early provincial program. The historical data collected prior to 1984 in this corridor is available on compact disc. Please contact the Lower Mainland office at (604) 582-5200 to request a copy of this data.

In 1984, the first modern ambient air station was installed in Squamish, and included a dustfall collector, an acid precipitation monitor, and a nephelometer. This was followed by the installation of a Total Suspended Particulate (TSP) monitor, Total Reduced Sulphur (TRS) monitor, and wind and temperature sensors in the spring of 1985. For the remainder of the 1980s and early 1990s, the emission sources that received the greatest attention were pulp mills, and thus TRS monitoring was most prolific (at several different Howe Sound locations) in the Sea-to-Sky Airshed during this period.

By the late 1990s, two long-term stations were established in Squamish and Langdale as part of a permittee program for the two pulp and paper mills nearby. These stations now collectively measure ozone (O_3), nitrogen dioxide (NO_2), sulphur dioxide (SO_2), particulate matter under 10 microns (PM_{10}) in addition to Total Reduced Sulphur (TRS).

Historical measurements of ozone (O_3) in Pemberton, as well as present-day measurements of O_3 in Squamish, indicate that ozone concentrations in the Sea-to-Sky Airshed can often reach levels close to those experienced in the Fraser Valley, an area known for its degraded air quality episodes in summer. In order to understand more about ozone concentrations in the region and to assess the ozone concentrations north of Squamish, an O_3 monitor was also installed in Whistler in 2001. The installation of a NO_x monitor in Whistler (to assess what influence local NO_x emissions may be having on O_3 concentrations) followed in 2003. Further studies investigating ozone concentrations in the Sea-to-Sky Airshed are expected in 2005-06.

Figure 2.1 illustrates the distribution of historic and present-day monitoring and meteorological stations in the Sea-to-Sky corridor at the end of 2001. A detailed listing of all of these stations is presented in Table 2.1, and includes information about the parameters measured at each site.

Figure 2.1: Historical and Present-day MWLAP Ambient Monitoring Stations and Meteorological Stations in the Sea-to-Sky Airshed. The Upper and Lower Sea-to-Sky Airshed boundaries are depicted as thick, black lines.

Figure 2.1: Historical and Present-day MWLAP Ambient Monitoring Stations and Meteorological Stations in the Sea-to-Sky Airshed. The Upper and Lower Sea-to-Sky Airshed boundaries are depicted as thick, black lines.

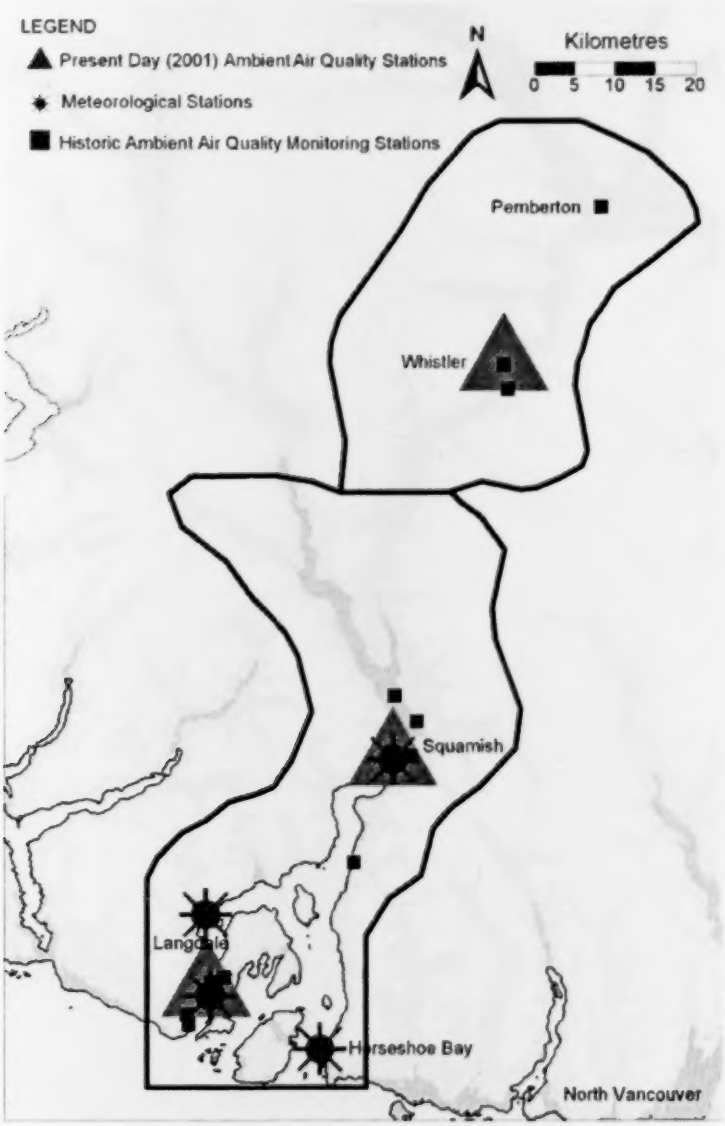


Table 2.1: Meteorological and Ambient Air Monitoring Stations in the Sea-to-Sky Airshed, 1984-2001.

ID	Station Name	Dates Operational	SO_2	TRS (H_2S)	NO_x	O_3	PM_{10}	Dust (TSP)	Wind	Temp	RH
n/a	Gambier Island	1996 -1997		✓							
E217061	Gibsons Firehall	1992-1995		✓			✓				
E217062	Gibsons Townhall	1993-1994	✓	✓							
E206800	Horseshoe Bay Ferry Terminal	1986 to 1988		✓							
E206164	Horseshoe Bay Firehall	1984 -1988		✓				✓			
E207302	Horseshoe Bay Isleview Dr.	1987-1991		✓							
E206758	Horseshoe Bay Libby Lodge	1986		✓							
E206298	Horseshoe Bay Madrona Cr.	1985-1986		✓							
M104271	Horseshoe Bay Water Tower	1985-1987							✓	✓	
E222778	Langdale Elementary	1995-present	✓	✓	✓		✓				
M104273	Langdale Ferry Terminal	1987-1996							✓	✓	
E206987	Langdale YMCA	1990-1995		✓			✓	✓			
E206167	Pemberton	1984-1986				✓					
E226338	Port Mellon	1997-present							✓	✓	
E206986	Porteau Cove	1987-1993		✓							
E247662	Squamish Brackendale	1997					✓				
E247663	Squamish Garibaldi	1997					✓				
0310172	Squamish	1985-present	✓	✓		✓	✓	✓			
M104270	Squamish	1985-present							✓	✓	✓
n/a	Squamish Valleycliffe	1997					✓				
E227431	Whistler Meadow Park	2001-present				✓					
n/a	Whistler Townhall	1994-1995					✓				

3.0 AIR QUALITY OBJECTIVES

Both the National and Provincial governments have ambient air quality objectives which are intended to ensure long-term protection of public health and the environment. These objectives were established for Criteria (or Common) Air Contaminants (CACs) using the categories "desirable", "acceptable" and "tolerable" for the National objectives, and Levels A, B and C for the Provincial objectives. The Desirable and Level A objectives are the most stringent and protective. In general, the three Provincial categories follow the same objective levels as the three National categories. The general meaning/definitions of the Provincial and National Objectives are described in Table 3.1.

Table 3.1: Descriptive Definitions of the Provincial and National Air Quality Objectives.

Jurisdiction	Objective	Objective Description*
Provincial	Level A (most protective)	Provides long-term environmental protection. Required for new and proposed discharges and, within the limits of the best practicable technology, to existing discharges by planned staged improvements for these operations.
	Level B	Provides adequate protection against adverse effects on human health, vegetation and animals. Usually set as an intermediate objective for all existing discharges to reach within a specified time period, and as an immediate objective for existing discharges which may be increased in quantity or altered in quality as a result of process expansion or modification.
	Level C	Appropriate action is necessary to protect the health of the general population.
National	Maximum Desirable	Long-term goal for air quality that provides a basis for an anti-degradation policy for unpolluted parts of the country and for continuing development of control technology.
	Maximum Acceptable	Provides adequate protection against adverse effects on soil, water, vegetation, materials, animals, visibility, personal comfort and well-being.
	Maximum Tolerable	Denotes time-based concentrations of air contaminants beyond which, due to a diminishing margin of safety, appropriate action is required without delay to protect the health of the general population.

* Source: EcoLog Canadian Pollution Legislation (www.ecolog.com)

The Provincial and National air quality objectives for the following pollutants measured in the Sea-to-Sky Airshed are presented in Table 3.2: SO_2 (sulphur dioxide), TRS (total reduced sulphur), NO_2 (nitrogen dioxide), O_3 (ozone), and PM_{10} (fine particulate matter under 10 microns in diameter). While objectives for CO (carbon monoxide) also exist, this pollutant was not historically measured in this airshed and is presently not being monitored because emission sources for this pollutant are low and it is not presently a concern in the ambient environment.

3.1 Canada-Wide Standards

Canada-Wide Standards (CWS) are national objectives that were established pursuant to the Canada-Wide Accord on Environmental Harmonisation of the Canadian Council of Ministers of the Environment (CCME) and its Canada-Wide Environmental Standards Sub-Agreement[1]. The CWS are intended to provide long-range targets for Ozone and $PM_{2.5}$ management, and represent a balance between the desire to protect human health and the environment in the near-term and the costs of reducing pollutant emissions.

The CWS for Ozone is 65 ppb (approx. 130 $\mu g/m^3$) (8-hour average), based on the 4th highest measurement annually, averaged over three consecutive years. For a given reporting area, the station with the highest average ozone concentration is used. In the Sea-to-Sky Airshed, the Squamish station

has more than 3 years of ozone data available with which to calculate the CWS for Ozone. In the future, this calculation may be done for Whistler and Pemberton as well.

The CWS for $PM_{2.5}$ is 30 $\mu g/m^3$ (24-hour average), based on the annual 98th percentile value, averaged over three consecutive years. Measurement of $PM_{2.5}$ was not conducted in the Sea-to-Sky Airshed for this reporting period.

Table 3.2: National and Provincial Air Quality Objectives for Criteria Air Contaminants measured in the Sea-to-Sky Airshed.

Pollutant	Averaging Period	Federal Objectives			Provincial Objectives		
		Maximum Desirable ($\mu g/m^3$)	Maximum Acceptable ($\mu g/m^3$)	Maximum Tolerable ($\mu g/m^3$)	Level A ($\mu g/m^3$)	Level B ($\mu g/m^3$)	Level C ($\mu g/m^3$)
Sulphur dioxide (SO_2)	1 hour	450	900		450	900	900-1300
	24 hour	150	300	800	160	260	360
	annual	30	60		25	50	80
Total Reduced Sulphur (TRS)	1 hour				7	28	
	24 hour				3	6	
Nitrogen Dioxide (NO_2)	1 hour		400	1000			
	24 hour		200	300			
	annual	60	100				
Ozone (O_3)	1 hour	100	160	300			
	24 hour	30	50				
	Annual		30				
Particulate Matter (PM_{10})	24 hour					50	
	annual						
Total Suspended Particulate (TSP)	24 hour		120	400	150	200	260
	annual	60	70		60	70	75

3.2 Reference Levels

The Canadian Environmental Protection Act (CEPA) Federal-Provincial Working Group on Air Quality Objectives and Guidelines published a report in 1998 to evaluate the most recent health and epidemiological studies relating to Particulate Matter and Ozone and to review the National Ambient Air Quality Objectives for these two pollutants. In the Addendum to their Science Assessment Document: National Air Quality Objectives for Particulate Matter (1999)[2] and for Ozone (1999)[3], they identified the 'lowest observed adverse effect levels' (LOAEL), which are health based levels at which statistically significant adverse effects on human health can be detected. These are also known as Health Reference Levels. The Health Reference Levels for PM_{10} and $PM_{2.5}$ are 25 $\mu g/m^3$ and 15 $\mu g/m^3$ respectively, based on a 24-hour averaging period.

4.0 METEOROLOGICAL DATA SUMMARY

Meteorological data is presently being measured in Squamish, and historically was measured in Langdale, Horseshoe Bay, Port Mellon and Woodfibre (it continues to be monitored in Port Mellon and Woodfibre, but these are considered to be non-standard stations). Future plans for meteorological stations include a permanent installation at Horseshoe Bay (with cooperation from the GVRD and Environment Canada), Pemberton and Whistler, and re-establishing the meteorological station in Langdale.

A summary of the historical meteorological data in the Sea-to-Sky Airshed is presented here on a station-by-station basis, followed by a summary for the whole region. This report presents a primary survey of the temperature and wind conditions in the region, and is not an exhaustive climatological survey. This data is of value for air quality modelling purposes, siting of emission sources, for correlation with air pollution episodes/sources, and for those wishing to gain a deeper understanding of the complex wind flows in Howe Sound and the surrounding mountain valleys.

4.1 Squamish

A meteorological station was installed in Squamish in June 1985. The meteorological tower is mounted on top of the Squamish Provincial Government Building at 30875 2nd Avenue. The tower is 7 m high, mounted on top of a 10.8 m building. The anemometer is mounted on the top of this tower (17.8 m above ground), and the temperature and relative humidity sensors are mounted 80 cm below the top of the tower. Photographs of the station are given in Appendix A. Table 4.1 contains a summary of the station information.

Table 4.1: Summary of Station Details for Squamish Meteorological Station.

Station Code	Address	Lat / Long	UTM (NAD 83)	Elevation (ASL)	Anemometer ht. (above ground)	Temp ht.
M104270	30875 2nd Ave. Squamish, BC	49° 41' 59" N 123° 09' 16" W	Zone 10 488879.6 5505278.7	10 m	17.8 m	17.0 m

4.1.1 Wind Speed and Direction

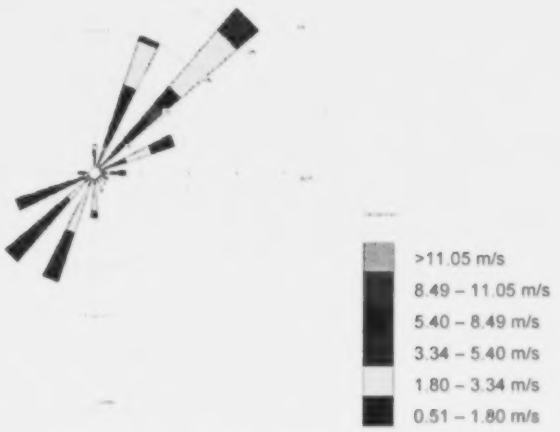
Wind data for the Squamish station was analyzed for the period June 1985 (installation) to December 2001. The original Aanderaa wind sentry system (separate cup and wind vane) was installed in 1985 at a height of 17.8 m above ground. The original datalogger program was re-written in 1996, resulting in a greater sensitivity to calm and light winds. The lowest threshold (lowest measured hourly wind speed) for the period between 1985 and 1996 was 0.4 m/s, while the lowest threshold from 1996 to present is < 0.1 m/s. Therefore the definition of 'calm' wind conditions (below anemometer threshold) was ≤ 0.4 m/s from 1985 to November 1996, and < 0.1 m/s from mid-November 1996 to present (for average hourly values). In 2001, the wind measurement system was changed from an Aanderaa wind sentry system to an RM Young Air Quality Standard Anemometer model 05305. Table 4.2 presents the percent valid data captured, the annual average wind speed, and the percentage of calm hours for each year of wind data measured. According to this table, the years since 1994 have had the least number of missing hours (1995 is the only complete year).

The winds measured at Squamish meteorological station are dominantly from the northeast. These winds are usually outflow winds from the Coast Mountains. Cold air that builds to the east of the Coast Mountains pours out through passes and valleys (past Lillooet and Pemberton), past Squamish into Howe Sound (*Lange, 1998*). A wind rose showing the frequency of wind speeds and directions measured between 1986 (1985 was excluded because of a large data gap) and 2001 is presented in Figure 4.1. Wind roses summarizing the frequency and direction of winds measured at Squamish station for each year are given in Appendix B. To determine if a particular year is representative of average wind conditions, annual wind roses in Appendix B may be compared with the wind rose shown in Figure 4.1.

Table 4.2: Percentage of Valid Data Captured, Annual Average Wind Speed, and Percentage of Calm Winds for Each Year of Measured Wind Data at Squamish Meteorological Station from 1985 to 2001.

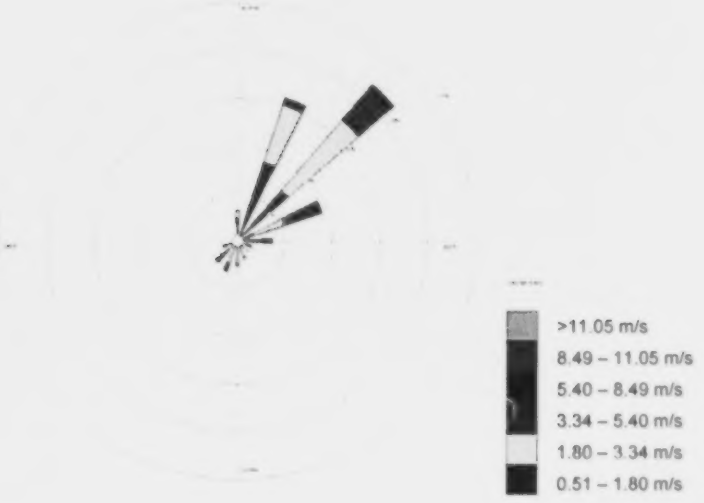
Year	% Data Capture	Average Wind Speed (m/s)	% Calm (0 m/s) Winds
1985	58.79	3.22	0.00
1986	99.93	2.87	0.00
1987	91.85	2.84	0.07
1988	96.11	2.79	0.00
1989	95.11	2.95	0.03
1990	99.28	2.98	0.06
1991	96.24	2.96	0.01
1992	97.22	2.93	0.85
1993	94.40	2.79	2.42
1994	99.73	2.77	1.32
1995	100.00	3.07	0.23
1996	98.33	3.22	0.09
1997	99.83	2.80	0.00
1998	99.74	3.03	0.00
1999	99.67	2.79	3.23
2000	99.54	2.87	0.49
2001	97.98	2.93	0.00

Figure 4.1: Frequency and Direction of Winds Measured at Squamish Meteorological Station from 1986 to 2001. (The total length of each 'petal' is indicative of the relative frequency of occurrence of winds *from* that direction; for a given wind direction, each colour represents the relative proportion of wind speed ranges.)



The northeasterly winds at Squamish dominate in the winter, when temperatures over the Chilcotin plateau are cold, and a ridge of high pressure sits over the interior of British Columbia[4]. Figure 4.2 shows the wind rose for the winter months (December, January, February) for the years 1986 to 2001. While there are occasional winds from the south and southwest during this winter period, these are most likely attributable to passing fronts and are generally short-lived.

Figure 4.2: Frequency and Direction of Winter (December, January, February) Winds Measured at Squamish Meteorological Station from 1986 to 2001. (The total length of each 'petal' is indicative of the relative frequency of occurrence of winds *from* that direction; for a given wind direction, each colour represents the relative proportion of wind speed ranges.)



As shown in Figure 4.1, winds in Squamish can also blow from the southwest, but this generally occurs during the summer months. In the summer, daytime heating of the mountain slopes around Howe Sound draws air up into the mountains (a reversal of the winter situation). This air is drawn up into the mountains in a cumulative process, such that winds gain more speed as they approach Squamish at the head of Howe Sound[4]. This can be seen in Figure 4.1, where the southwesterly winds, although fewer in frequency, are much stronger (see colour legend) than the northeasterly outflow winds. A wind rose showing only the daytime (10am to 7pm) summer (June to August) winds from 1986 to 2001 is presented in Figure 4.3. This figure shows that winds measured in Squamish are almost exclusively from the southwest in summer daytime conditions. At night, however, as the mountain slopes cool, there is a reversal in the wind flow similar to winter outflow conditions. A wind rose showing the night-time (midnight to 7am) summer (June to August) winds from 1986 to 2001 is presented in Figure 4.4. This figure, when grouped with Figure 4.3, gives a comprehensive picture of the summertime land-sea breeze that occurs in Squamish.

Figure 4.3: Frequency and Direction of Summer (June, July, August) Daytime (10am to 7pm) Winds Measured at Squamish Meteorological Station from 1986 to 2001. (The total length of each 'petal' is indicative of the relative frequency of occurrence of winds *from* that direction; for a given wind direction, each colour represents the relative proportion of wind speed ranges.)

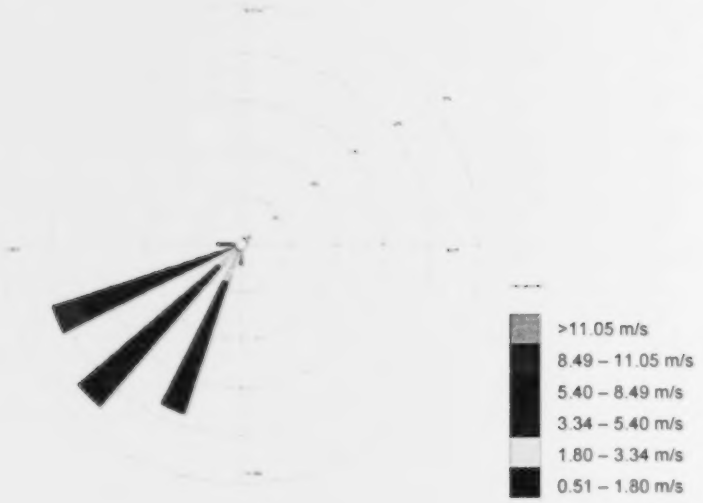
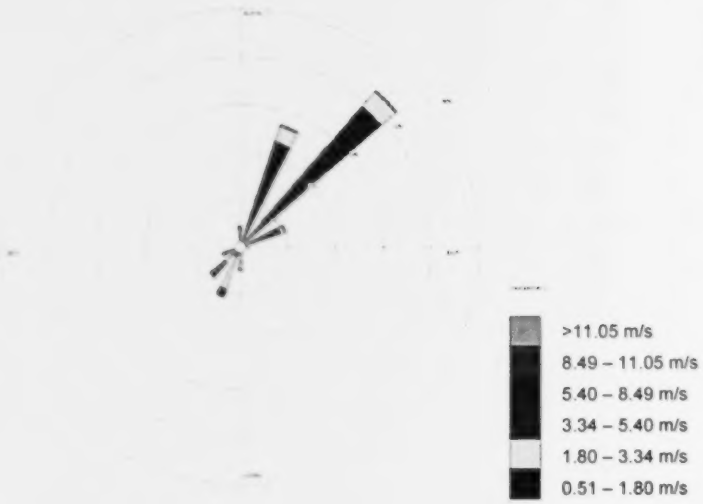


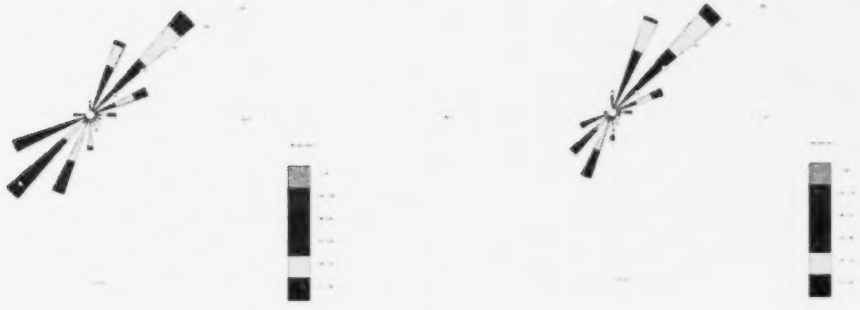
Figure 4.4: Frequency and Direction of Summer (June, July, August) Night time (Midnight to 7am) Winds Measured at Squamish Meteorological Station from 1986 to 2001. (The total length of each 'petal' is indicative of the relative frequency of occurrence of winds *from* that direction; for a given wind direction, each colour represents the relative proportion of wind speed ranges.)



The wind roses for the spring and fall conditions at Squamish station are a mix of both northeasterly and southwesterly winds. During the spring months (March, April, May), the southwesterly flows are slightly more dominant than in the fall months (September, October, November). The spring and fall wind roses for 1986 to 2001 are presented in Figure 4.5a and b.

Figure 4.5: Frequency and Direction of **(a)** Spring (March, April, May) and **(b)** Fall (September, October, November) Winds Measured at Squamish Meteorological Station from 1986 to 2001. (The total length of each 'petal' is indicative of the relative frequency of occurrence of winds *from* that direction; for a given wind direction, each colour represents the relative proportion of wind speed ranges.)

(a) (b)



4.1.2 Temperature

Temperature data for the Squamish station was analyzed for the period June 1985 (installation) to December 2001. Table 4.3 summarizes the annual percent data capture, the annual minimum and maximum temperatures, and the annual temperature mean and standard deviation. Minimum and maximum temperatures are reported as the individual lowest and highest temperature readings taken over a 1-year period, and the annual mean and standard deviation are reported as the arithmetic mean and standard deviation of the 12 monthly mean values for that year (according to WMO Technical Regulation 4.2.4 found at http://www.wmo.ch/web/wcp/ccl/GuideHome/html/wmo100.html).

Please note that the *mean temperatures in this report are computed as the arithmetic mean* and the standard deviation is reported as the root-mean-square of the deviations from the arithmetic mean. *The mean daily temperatures reported in many climatological normals (including Environment Canada meteorological stations) are given by the average of the daily maximum and minimum temperatures.* Thus an additional mean is given for WLAP stations called the "thermometer mean daily temperature" which is the average of the daily maximum and minimum temperatures that would normally be calculated for a station equipped with only a max-min thermometer. These "thermometer means" may be used to compare directly with climatological normals computed at non-automated stations and those of Environment Canada. WMO recommends calculation of an arithmetic mean when 24-hour data is available (Section 5.2.4.1.1), which has been done in this report. This calculation also provides a more reliable method for assessing trends related to longer term averages such as climate change.

Table 4.3: Percentage of Valid Data Captured, Annual Minimum and Maximum Temperatures, and Annual Temperature Mean and Standard Deviation for Each Year Measured at Squamish Meteorological Station from 1985 to 2001.

Year	% Data Capture	Minimum (°C)	Maximum (°C)	Mean (°C)	Std Dev (°C)
1985	58.88	-14.0	30.7	n/a	n/a
1986	99.93	-11.6	30.9	9.7	5.4
1987	99.83	-5.9	30.7	10.4	5.2
1988	99.68	-6.0	34.5	10.0	5.0
1989	99.97	-14.5	32.6	9.5	6.1
1990	100.00	-13.0	32.1	9.5	6.7
1991	96.26	-9.0	31.9	10.1	5.6
1992	97.12	-8.9	31.7	11.1	5.6
1993	94.54	-11.0	35.8	8.2	5.9
1994	100.00	-7.3	29.4	9.8	5.9
1995	100.00	-6.6	30.8	10.2	5.5
1996	98.13	-11.6	30.6	9.3	6.3
1997	99.87	-10.6	29.8	9.7	5.8
1998	99.82	-9.2	30.4	10.3	6.0
1999	99.85	-1.7	26.9	9.1	5.0
2000	99.51	-5.7	27.0	9.2	5.5
2001	97.96	-4.0	31.4	9.3	5.7

For the averaging period 1985 to 2001 (15.5 years), the climatological statistics are presented in Table 4.4. While this averaging period is about half of a true climatological period (30 years), these statistics nonetheless provide a reasonable history for comparative purposes. The data were processed according to WMO standards for missing data.

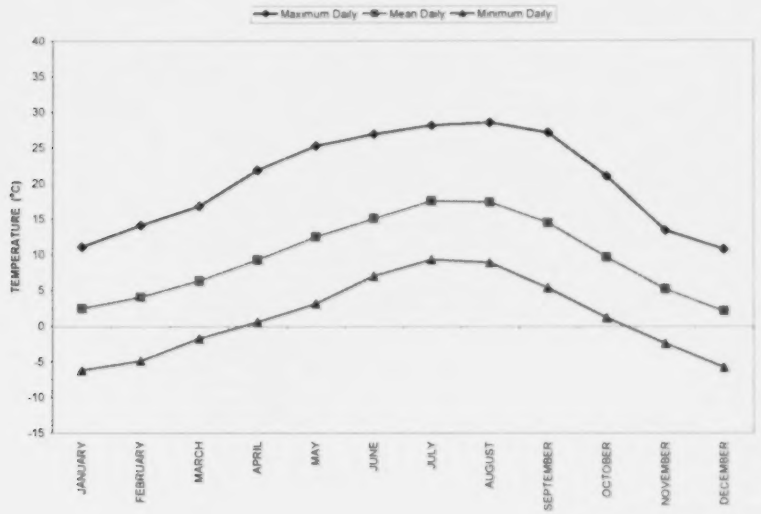
Table 4.4: Provisional Climatological Temperature Normals (1985 to 2001) for Squamish Meteorological Station.

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Arithmetic Mean Daily Temperature (°C)	2.5	4.0	6.3	9.3	12.5	15.1	17.5	17.4	14.5	9.6	5.2	2.1
Standard Deviation (°C)	3.2	3.4	3.3	3.7	3.8	3.6	3.6	3.6	3.8	3.5	3.2	3.2
Maximum Daily Temperature (°C)	11.1	14.1	16.8	21.9	25.2	26.9	28.1	28.5	27.1	21.0	13.4	10.7
Minimum Daily Temperature (°C)	-6.2	-4.9	-1.8	0.6	3.1	7.0	9.3	8.9	5.3	1.1	-2.4	-5.8
Thermometer Mean Daily Temperature (°C)	2.4	4.6	7.5	11.2	14.2	16.9	18.7	18.7	16.2	11.1	5.5	2.5

On average, the difference between the thermometer mean and arithmetic mean daily temperatures is 1.15°C, with the maximum differences occurring in the warmer months (+1.96°C) and the minimum differences occurring in the colder months (-0.03°C).

The data presented in tabular form in Table 4.4 is also presented graphically in Figure 4.6. Note that the arithmetic mean is used in this graph. In general, the mean daily temperatures in Squamish remain above freezing (0°C) year-round. Minimum temperatures are below freezing for the winter months (November through March), and above freezing for the remainder of the year. These mild temperatures can be attributed to the moderating influences of the ocean.

Figure 4.6: Maximum, Minimum and Mean Daily Temperatures Measured At Squamish Meteorological Station from 1985 to 2001.



4.2 Langdale

A meteorological station was installed at the BC Ferry Terminal in Langdale in December 1987 and decommissioned in February 1998. Measurement will commence again at this station in 2004. The meteorological tower was mounted on top of a tower at the ferry terminal at a height of approximately 18 m above ground (no record of the measurement height exists – estimate is based on photographs). Photographs of the station are given in Appendix A. Table 4.5 contains a summary of the station information.

Table 4.5 Summary of Station Details for Langdale Meteorological Station.

Station Code	Address	Lat / Long	UTM (NAD 83)	Elevation (ASL)	Anemometer ht. (above ground)	Temp ht.
M104273	1376 Port Mellon Hwy. Langdale, BC.	49° 26' 03" N 123° 28' 15" W	Zone 10 465739.0 5475729.0	4 m	~ 18 m	~ 8m

4.2.1 Wind Speed and Direction

Wind data for the Langdale station was analyzed for the period January 1988 (one month after installation) to December 1997 (decommissioned). The original Aanderaa wind sentry system was installed in 1985, although the data logger programming was updated 1995/96 to increase the sensitivity to light and calm winds. The lowest threshold (lowest measurable average hourly wind speed) for the anemometer in 1985 was 0.4 m/s, while the lowest threshold after 1995 was < 0.1 m/s. Therefore the definition of 'calm' wind conditions (below anemometer threshold) was ≤ 0.4 m/s from 1988 to February 1995, and < 0.1 m/s from mid-February 1995 to December 1997.

Table 4.6 presents the percentage of valid data captured, the annual average wind speed, and the percentage of calm hours for each year of wind data measured.

Table 4.6: Percentage of Valid Data Captured, Annual Average Wind Speed, and Percentage of Calm Winds for Each Year of Measured Wind Data at Langdale Meteorological Station from 1988 to 1997.

Year	% Data Capture	Average Wind Speed (m/s)	% Calm (0 m/s) Winds
1988	99.91	2.49	0.00
1989	96.18	2.50	0.01
1990	94.63	2.53	0.32
1991	95.65	2.32	2.10
1992	91.13	2.51	0.00
1993	83.62	2.49	0.01
1994	99.57	2.64	0.02
1995	89.02	2.35	10.34
1996	92.27	2.46	7.04
1997	85.99	2.52	2.74

According to Table 4.6, there are no complete years of wind data for Langdale station, although 1994 and 1988 have over 99% data capture. The large increase in calm winds (0 m/s) that occurs in 1995 and 1996 is due to a change in the datalogger programming that was put into place in February 1995, and was changed again in June 1996. This data (1995 and 1996), while still contained in the data archive, is questionable and should not be used for modelling or trend analysis. Wind roses summarizing the frequency and direction of winds measured at Langdale station for each year are given in Appendix C. To determine if a particular year is representative of average climatological conditions, annual wind roses in Appendix C may be compared with a summary wind rose (for the entire period from 1988 to 1997) shown in Figure 4.7.

The winds measured at Langdale meteorological station are dominantly from the northwest. In general, the outflow winds that blow from the northeast past Squamish and into Howe Sound are deflected by land masses (e.g. Anvil Island, Gambier Island), and these winds are generally thought to follow the path on the eastern side of the sound through Montagu and Queen Charlotte Channels (the conditions under which the flow shifts into Thornbrough Channel are not well understood)[4]. On the southwestern side of Howe Sound, winds are generally calmer (winds in Squamish average 2.9 m/s, while at Langdale they average 2.5 m/s). The relative shelter offered by Gambier Island creates a situation whereby the dominant winds in Langdale are from outflow winds from the river valleys to the west and northwest of the ferry terminal. Winds from the south and south-southwest primarily occur in summer-daytime conditions where daytime heating of the mountain slopes around Howe Sound draws air up the sound and into the mountains. A wind rose showing the frequency of wind speeds and directions measured between 1988 and 1997 is presented in Figure 4.7.

North to northwesterly winds dominate in the winter in Langdale. These winds are most likely attributable to outflow winds from the surrounding valleys on the western shores of Howe Sound. Figure 4.8 shows the wind rose for the winter months (December, January, February) for the years 1988 to 1997. While there are occasional winds from the south during this winter period, these are most likely attributable to passing fronts and are generally short-lived.

As shown in Figure 4.7, winds in Langdale can also blow from the south, but this generally occurs during the summer months. In the summer, daytime heating of the mountain slopes around Howe Sound draws air up into the sound and the surrounding mountains. The southerly summer daytime (10am to 7pm) winds in Figure 4.9 are much faster (see colour legend) than the westerly and northwesterly outflow and night-time winds. A wind rose showing the night-time (midnight to 7am) summer (June to August) winds from 1988 to 1997 is presented in Figure 4.10. These two figures do not present a traditional 'mirror-opposite' land-sea breeze circulation due to deflection of the winds by land masses in the southwestern region of Howe Sound.

Figure 4.7: Frequency and Direction of Winds Measured at Langdale Meteorological Station from 1988 to 1997. (The total length of each 'petal' is indicative of the relative frequency of occurrence of winds *from* that direction; for a given wind direction, each colour represents the relative proportion of wind speed ranges.)

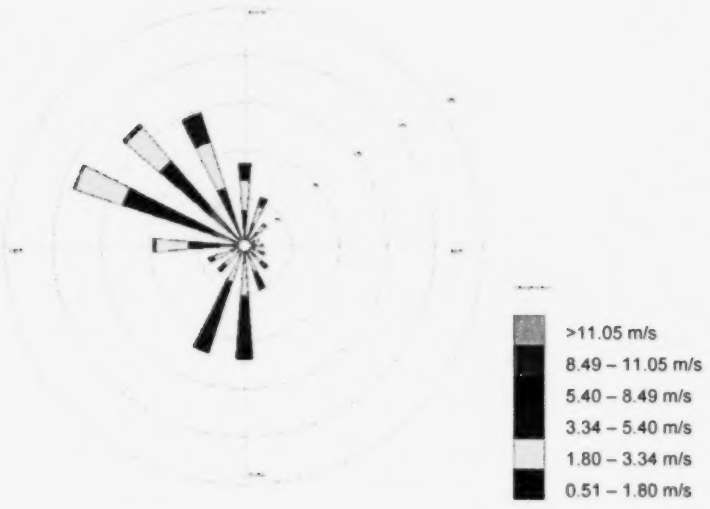


Figure 4.8: Frequency and Direction of Winter (December, January, February) Winds Measured at Langdale Meteorological Station from 1988 to 1997. (The total length of each 'petal' is indicative of the relative frequency of occurrence of winds *from* that direction; for a given wind direction, each colour represents the relative proportion of wind speed ranges.)

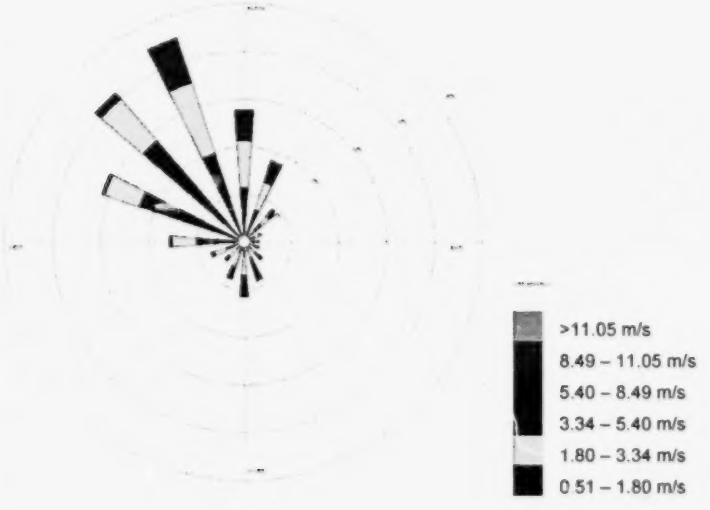


Figure 4.9: Frequency and Direction of Summer (June, July, August) Daytime (7am to 10pm) Winds Measured at Langdale Meteorological Station from 1988 to 1997. (The total length of each 'petal' is indicative of the relative frequency of occurrence of winds *from* that direction; for a given wind direction, each colour represents the relative proportion of wind speed ranges.)

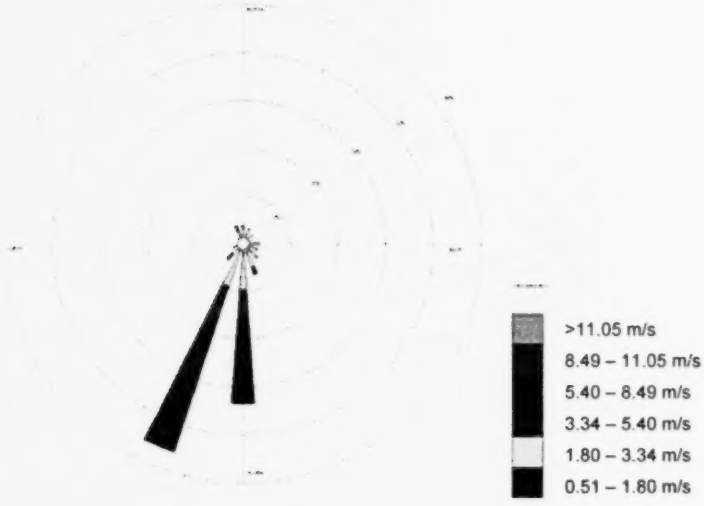
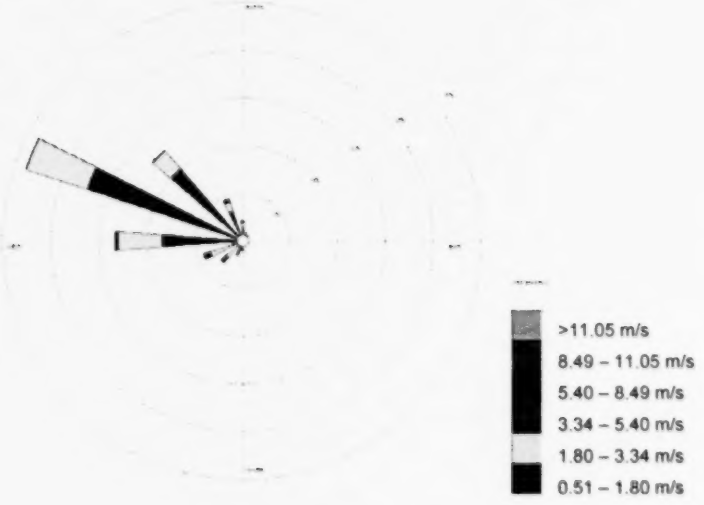


Figure 4.10: Frequency and Direction of Summer (June, July, August) Night time (Midnight to 7am) Winds Measured at Langdale Meteorological Station from 1988 to 1997. (The total length of each 'petal' is indicative of the relative frequency of occurrence of winds *from* that direction; for a given wind direction, each colour represents the relative proportion of wind speed ranges.)



4.2.2 Temperature

Temperature data for the Langdale station was analyzed for the period September 1987 (installation) to February 1998 (decommissioned). Table 4.7 summarizes the annual percent data capture, the annual minimum and maximum temperatures, and the annual temperature mean and standard deviation. Minimum and maximum temperatures are reported as the individual lowest and highest 1-hour temperature readings during a 1-year period, and the mean and standard deviation are reported as the arithmetic mean and standard deviation of the 12 monthly mean values (according to WMO Technical Regulation 4.2.4).

Table 4.7: Percentage of Valid Data Captured, Annual Minimum and Maximum Temperatures, and Annual Temperature Mean and Standard Deviation for Each Year Measured at Langdale Meteorological Station from 1987 to 1998.

Year	% Data Capture	Minimum (°C)	Maximum (°C)	Mean (°C)	Std Dev (°C)
1987	23.08	n/a	n/a	n/a	n/a
1988	99.91	-4.8	28.5	10.3	5.5
1989	96.16	-11.2	30.0	10.3	6.0
1990	94.76	-10.4	31.1	9.8	6.6
1991	99.75	-5.3	28.1	10.2	5.6
1992	91.12	-4.5	27.0	11.5	5.7
1993	85.32	-7.1	27.2	10.3	6.0
1994	99.58	-4.7	27.5	10.9	5.8
1995	89.09	-3.1	29.1	16.6	8.4
1996	90.07	-6.8	26.5	15.0	6.7
1997	91.61	-5.8	27.7	10.5	5.7
1998	10.95	n/a	n/a	n/a	n/a

Note that the *mean temperatures in this report are computed as the arithmetic mean* and the standard deviation is reported as the root-mean-square of the deviations from the arithmetic mean. *The mean daily temperatures reported in many climatological normals (including Environment Canada meteorological stations) are given by the average of the daily maximum and minimum temperatures.* Thus an additional mean is given for WLAP stations called the "thermometer mean daily temperature" which is the average of the daily maximum and minimum temperatures that would normally be calculated for a station equipped with only a max-min thermometer. These "thermometer means" may be used to compare directly with climatological normals computed at non-automated stations and those of Environment Canada. WMO recommends calculation of an arithmetic mean when 24-hour data is available (Section 5.2.4.1.1). This calculation also provides a more reliable method for assessing trends related to longer term averages such as climate change.

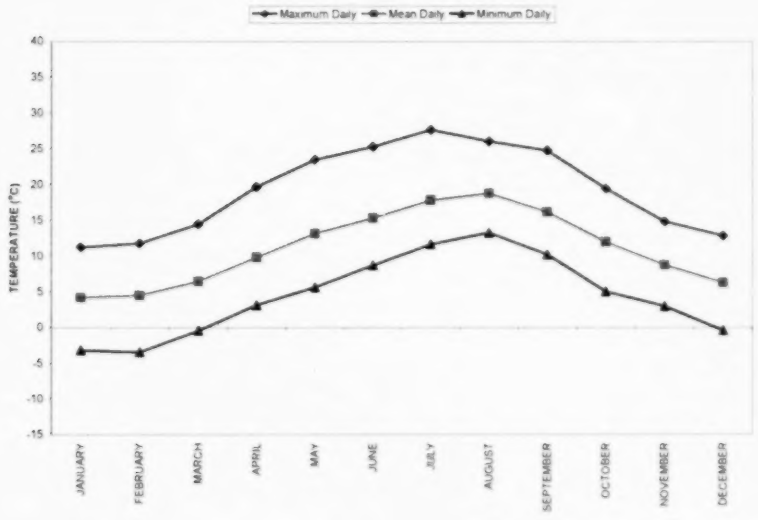
Climatological statistics for Langdale meteorological station for the years 1988 to 1997 are presented in Table 4.8. The data were processed according to WMO standards for missing data. On average, the difference between the thermometer mean and arithmetic mean daily temperatures is 0.9 °C, with the maximum differences occurring in the warmer months (for July, +1.8 °C) and the minimum differences occurring in the cooler months (between 0 and -0.3 °C).

The data presented in tabular form in Table 4.8 is also presented graphically in Figure 4.11. Note that the arithmetic mean is used in this graph. In general, the mean daily temperatures in Langdale remained above freezing (0 °C) year-round in during this 10 year period. Minimum temperatures were below freezing for the winter months (December through March), and above freezing for the remainder of the year.

Table 4.8: Provisional Climatological Temperature Normals (1988 to 1997) for Langdale Meteorological Station.

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Arithmetic Mean Daily Temperature (°C)	4.2	4.5	6.4	9.8	13.1	15.3	17.8	18.7	16.1	11.9	8.7	6.2
Standard Deviation (°C)	2.9	3.0	2.8	2.9	3.1	2.9	2.9	2.4	2.7	2.7	2.3	2.9
Maximum Daily Temperature (°C)	11.2	11.7	14.4	19.6	23.4	25.3	27.6	26.0	24.8	19.4	14.8	12.8
Minimum Daily Temperature (°C)	-3.2	-3.5	-0.5	3.1	5.6	8.7	11.6	13.2	10.2	5.0	2.9	-0.5
Thermometer Mean Daily Temperature (°C)	4.0	4.1	7.0	11.4	14.5	17.0	19.6	19.6	17.5	12.2	8.9	6.2

Figure 4.11: Maximum, Minimum and Mean Daily Temperatures Measured At Langdale Meteorological Station from 1988 to 1997



4.3 Horseshoe Bay

Meteorological data was collected in the community of Horseshoe Bay from 1985 to 1987. The meteorological tower was installed at the Horseshoe Bay water tower. No historical photographs or data relating to the station siting and installation exist. Therefore, station details are incomplete and are estimated based on anecdotal information. Table 4.9 contains a summary of the station information.

Table 4.9 Summary of Station Details for Horseshoe Bay Meteorological Station.

Station Code	Address	Lat / Long	UTM (NAD 83)	Elevation	Anemometer ht. (above ground)	Temp ht.
M104271	Unknown	49° 22' 22" N 123° 16' 47" W	Zone 10 479599.0 5468971.0	60 m	Unknown (~ 15 m)	Unknown

4.3.1 Wind Speed and Direction

Wind data for the Horseshoe Bay station was analyzed for the period June 1985 to February 1987 (decommissioned). The lowest programmed threshold (lowest measurable hourly wind speed) for the Aanderaa anemometer was 0.4 m/s. Therefore the definition of 'calm' wind conditions (below anemometer threshold) was equal to 0.4 m/s. Table 4.10 presents the percentage of missing hours, the annual average wind speed, and the percentage of calm hours for each year of wind data measured.

Table 4.10: Percentage of Valid Data Captured, Annual Average Wind Speed, and Percentage of Calm Winds for Each Year of Measured Wind Data at Horseshoe Bay Meteorological Station from 1985 to 1987.

Year	% Data Capture	Average Wind Speed (m/s)	% Calm (0.4 m/s) Winds
1985	54.58	n/a	n/a
1986	94.24	2.47	0.00
1987	10.83	n/a	n/a

According to Table 4.10, the only full year for which there is wind data is 1986. A wind rose summarizing the frequency and direction of winds measured at Horseshoe Bay station for 1986 is shown in Figure 4.12.

As seen in Figure 4.12, the winds measured in 1986 at Horseshoe Bay meteorological station are dominantly from the northeast. These winds are usually outflow winds from the Coast Mountains. Cold air that builds to the east of the Coast Mountains pours out through passes and valleys (past Pemberton and Squamish) into Howe Sound[4]. Winds flow out of Howe Sound and pass over Horseshoe Bay from the northeast. The south and southwesterly winds are likely attributable to summer daytime winds, while the stronger winds from the southeast may be from outflow winds from neighbouring valleys/straits or frontal passages. These southeasterly winds are present in both daytime and nighttime summer conditions, and in all seasons. They are therefore most likely attributable to flow from the Strait of Georgia/English Bay north/northwest towards Horseshoe Bay.

The north and northeasterly winds dominate in the winter, when temperatures over the Chilcotin plateau are cold, and a ridge of high pressure sits over the interior of British Columbia[4]. Figure 4.13 shows the wind rose for the winter months (December, January, February) for the year 1986. Winds from the southeast during this winter period may also be outflow winds from neighbouring valleys (the terrain is very complex around Horseshoe Bay) or flow from the Strait of Georgia/English Bay. Data for the Horseshoe Bay station is limited to one year, and therefore long term wind flow patterns are difficult to discern without further measurement.

As shown in Figure 4.12, winds in Horseshoe Bay can also blow from the south and southwest, but sustained winds from these directions generally occur during the summer months. In the summer, daytime heating of the mountain slopes around Howe Sound draws air up into the mountains (a reversal of the winter situation)[4]. This air is drawn up into the mountains in a cumulative process, such that winds are slower at the mouth of Howe Sound, and gain more speed as they approach Squamish. A wind rose showing only the daytime (10am to 7pm) summer (June to August) winds in 1986 is presented in Figure 4.14. This figure shows that winds measured in Horseshoe Bay are almost exclusively from the south and southwest in summer daytime conditions.

Figure 4.12: Frequency and Direction of Winds Measured at Horseshoe Bay Meteorological Station in 1986 only. (The total length of each 'petal' is indicative of the relative frequency of occurrence of winds *from* that direction; for a given wind direction, each colour represents the relative proportion of wind speed ranges.)

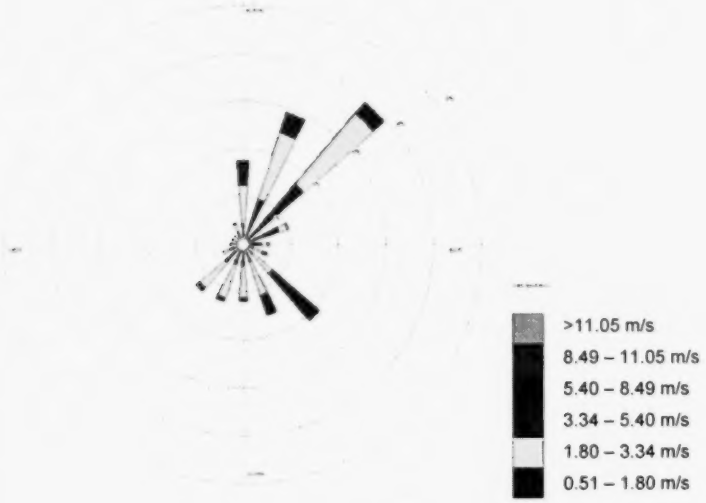


Figure 4.13: Frequency and Direction of Winter (December, January, February) Winds Measured at Horseshoe Bay Meteorological Station in 1986 only. (The total length of each 'petal' is indicative of the relative frequency of occurrence of winds *from* that direction; for a given wind direction, each colour represents the relative proportion of wind speed ranges.)

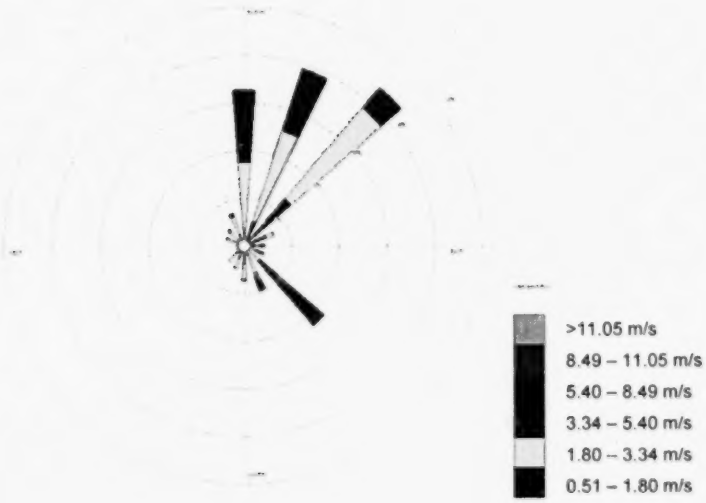


Figure 4.14: Frequency and Direction of Summer (June, July, August) Daytime (10am to 7pm) Winds Measured at Horseshoe Bay Meteorological Station in 1986 only. (The total length of each 'petal' is indicative of the relative frequency of occurrence of winds *from* that direction; for a given wind direction, each colour represents the relative proportion of wind speed ranges).

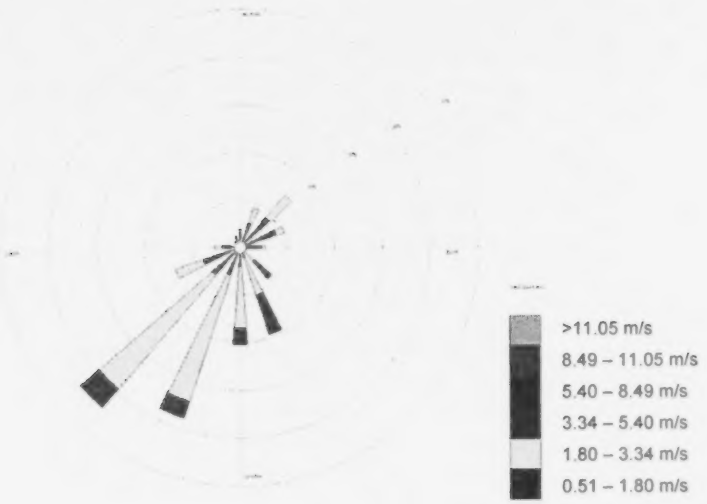
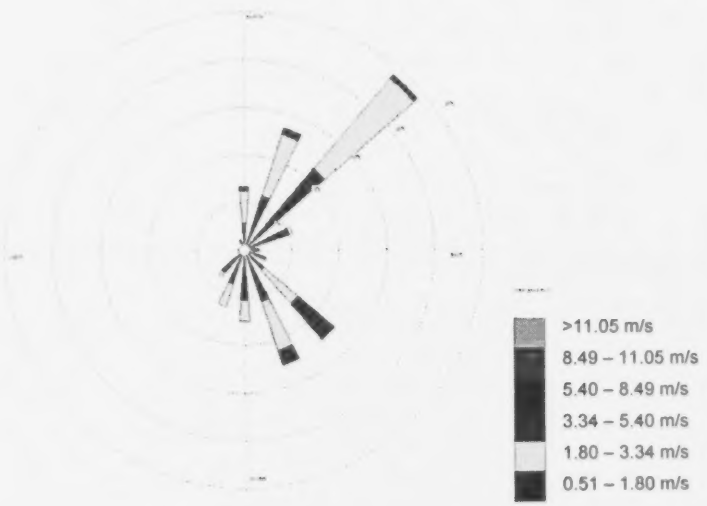


Figure 4.15: Frequency and Direction of Summer (June, July, August) Nighttime (Midnight to 7am) Winds Measured at Horseshoe Bay Meteorological Station in 1986 only. (The total length of each 'petal' is indicative of the relative frequency of occurrence of winds *from* that direction; for a given wind direction, each colour represents the relative proportion of wind speed ranges).



At night, however, as the mountain slopes cool, there is a reversal in the wind flow similar to winter outflow conditions. This is similar to the situation seen on the opposite side of Howe Sound at Langdale, although the outflow winds are from the northwest instead of the northeast. The southeast winds may also be a combination of outflow winds, passing fronts, or winds from the Strait of Georgia. A wind rose showing the night-time (midnight to 7am) summer (June to August) winds in 1986 is presented in Figure 4.15. This figure, when grouped with figure 4.14, gives a comprehensive picture of the summertime land-sea breeze that occurs in Horseshoe Bay.

4.3.2 Temperature

Temperature data for the Horseshoe Bay station was analyzed for the period June 1985 (installation) to February 1987 (decommissioned). Table 4.11 summarizes the annual percent data capture, the annual minimum and maximum temperatures, and the annual temperature mean and standard deviation. Minimum and maximum temperatures are reported as the individual lowest and highest 1-hour temperature readings taken over a 1-year period, and the mean and standard deviation are reported as the arithmetic mean and standard deviation of the 12 monthly mean values (according to WMO Technical Regulation 4.2.4).

Table 4.11: Percentage of Valid Data Captured, Annual Minimum and Maximum Temperatures, and Annual Temperature Mean and Standard Deviation for Each Year Measured at Horseshoe Bay Meteorological Station from 1987 to 1998.

Year	% Data Capture	Minimum (°C)	Maximum (°C)	Mean (°C)	Std Dev (°C)
1985	54.58	-17.6	29.7	n/a	n/a
1986	94.25	-5.9	30.1	10.8	5.50
1987	10.83	n/a	n/a	n/a	n/a

Please note that the *mean temperatures in this report are computed as the arithmetic mean* and the standard deviation is reported as the root-mean-square of the deviations from the arithmetic mean. *The mean daily temperatures reported in many climatological normals (including Environment Canada meteorological stations) are given by the average of the daily maximum and minimum temperatures.* Thus an additional mean is given for WLAP stations called the "thermometer mean daily temperature" which is the average of the daily maximum and minimum temperatures that would normally be calculated for a station equipped with only a max-min thermometer. These "thermometer means" may be used to compare directly with climatological normals computed at non-automated stations and those of Environment Canada. WMO recommends calculation of an arithmetic mean when 24-hour data is available (Section 5.2.4.1.1). This calculation also provides a more reliable method for assessing trends related to longer term averages such as climate change.

Climatological statistics for Horseshoe Bay meteorological station for one complete year (1986) are presented in Table 4.12. No other data was available, and the data from 1985 and 1987 are incomplete. The data were processed according to WMO standards for missing data.

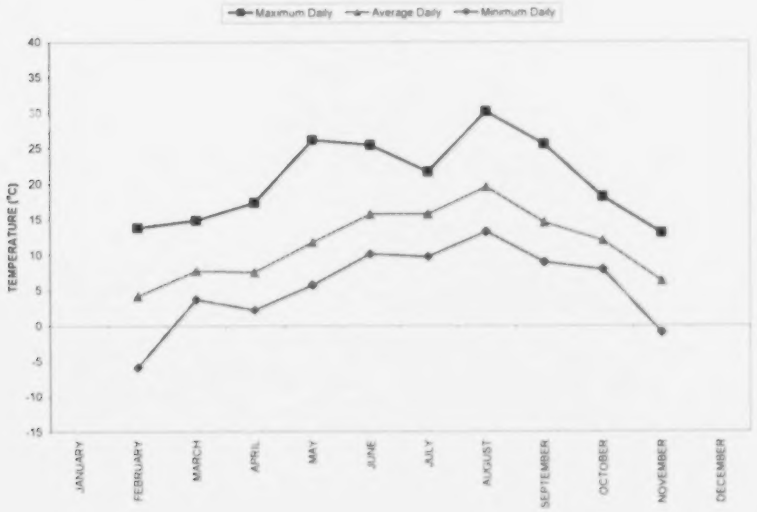
Table 4.12: Monthly Temperatures (1986 only) for Horseshoe Bay Meteorological Station.

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Arithmetic Mean Daily Temperature (°C)	n/a	4.2	7.7	7.5	11.8	15.7	15.7	19.5	14.5	11.9	6.3	n/a
Standard Deviation (°C)	n/a	4.2	1.8	2.2	3.7	2.9	2.2	3.1	3.2	1.7	2.4	n/a
Maximum Daily Temperature (°C)	n/a	13.8	14.8	17.3	26.1	25.4	21.6	30.1	25.5	18.1	13.0	n/a
Minimum Daily Temperature (°C)	n/a	-5.9	3.7	2.2	5.7	10.1	9.7	13.2	8.9	7.9	-1.0	n/a
Thermometer Mean Daily Temperature (°C)	n/a	4.0	9.3	9.8	15.9	17.8	15.7	21.7	17.2	13.0	6.0	n/a

On average, the difference between the thermometer mean and arithmetic mean daily temperatures is 1.5 °C, with the maximum differences occurring in September (+2.7 °C) and the minimum differences occurring in February, July, and November (between 0 and -0.3 °C).

The data presented in tabular form in Table 4.12 is also presented graphically in Figure 4.16. Note that the arithmetic mean is used in this graph. In general, the mean daily temperatures in Horseshoe Bay remained above freezing (0 °C) year-round in 1986. Minimum temperatures were below freezing for the winter months (November through February, although data is incomplete), and above freezing for the remainder of the year. The dip in the July temperatures is likely an anomaly for this particular year (data from Squamish station in 1986 supports this statement), and may not be reflective of the average climatological conditions for July in Horseshoe Bay.

Figure 4.16: Maximum, Minimum and Mean Daily Temperatures Measured At Horseshoe Bay Meteorological Station in 1986.



4.4 Port Mellon

A meteorological station was installed at the Howe Sound Pulp and Paper Mill in Port Mellon in the early 1990s, and this data was made available to the Ministry for archiving in 1997. The Port Mellon Meteorological Station is located on the north-northwestern side of the mill on the top of a crane overlooking piles of hog fuel. It is primarily intended to provide wind data related to the pulp mill's emissions. A photograph of the station can be found in Appendix A. Table 4.13 contains a summary of the station information. **This station is considered non-standard by the Ministry (due to its height and siting) and data from the station should be applied with caution**.

Table 4.13 Summary of Station Details for Port Mellon Meteorological Station.

Station Code	Address	Lat / Long	UTM (NAD 83)	Elevation	Anemometer ht. (above ground)	Temp ht.
E226338	Port Mellon, BC	49° 31' 22" N 123° 28' 56" W	Zone 10 465171.0, 5485830.0	3 m	31.85 m	31.85 m

4.4.1 Wind Speed and Direction

Wind data for the Port Mellon station was analyzed for the period May 1997 (commencement of Ministry archiving) to December 2001. The lowest threshold (lowest measurable hourly wind speed) for the Qualimetrics anemometer was 0.2 m/s, but the programming only resolved the wind speed to 0.4 m/s (like all other stations at that time). Therefore the definition of 'calm' wind conditions (below anemometer threshold) was equal to 0.4 m/s. Table 4.14 presents the percentage of missing hours, the annual average wind speed, and the percentage of calm hours for each year of wind data measured.

Table 4.14: Percentage of Valid Data Captured, Annual Average Wind Speed, and Percentage of Calm Winds for Each Year of Measured Wind Data at Port Mellon Meteorological Station from 1997 to 2001.

Year	% Data Capture	Average Wind Speed (m/s)	% Calm (0.4 m/s) Winds
1997	59.1	n/a	n/a
1998	65.2	2.41	0.0
1999	90.0	2.41	0.0
2000	94.7	2.41	0.0
2001	100.0	2.39	0.0

The winds measured at Port Mellon meteorological station are dominantly from the northwest. The height at which the winds are measured at this site is considerably higher than would be measured at a surface station (usually 10 m above ground – Port Mellon is nearly 40 m above ground). Thus outflow winds from the neighbouring river valley to the northwest of the mill dominate the measured winds at that height. The outflow winds that blow from the northeast past Squamish and into Howe Sound are deflected by land masses (e.g. Anvil Island, Gambier Island), and these winds are generally thought to follow the path on the eastern side of the sound through Montagu and Queen Charlotte Channels (the conditions under which the flow shifts into Thornbrough Channel are not well understood)[4]. On the southwestern side of Howe Sound, winds are generally calmer (winds in Squamish average 2.9 m/s, while at Langdale they average 2.5 m/s). The relative shelter offered by Gambier Island creates a situation whereby the dominant winds on the western shores of Howe Sound are from outflow winds from the river valleys to the west and northwest. Winds from the south and south-southwest primarily occur in summer-daytime conditions where daytime heating of the mountain slopes around Howe Sound draws air up the sound and into the mountains. A wind rose showing the frequency of wind speeds and directions measured between 1997 and 2001 is presented in Figure 4.17.

Figure 4.17: Frequency and Direction of Winds Measured at Port Mellon Meteorological Station from 1997 to 2001. (The total length of each 'petal' is indicative of the relative frequency of occurrence of winds *from* that direction; for a given wind direction, each colour represents the relative proportion of wind speed ranges.)

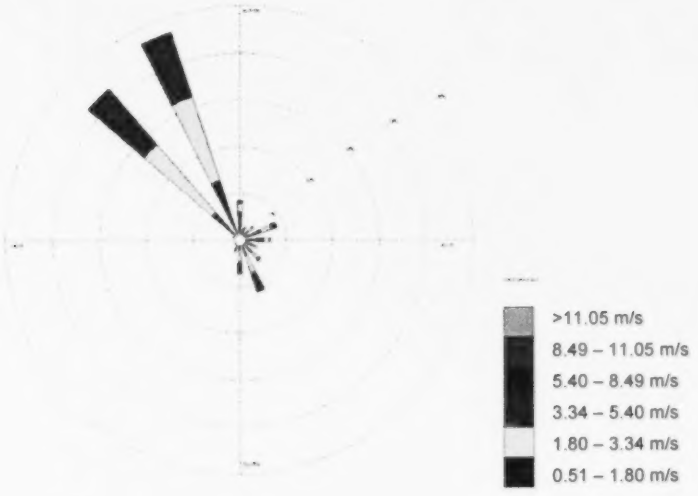


Figure 4.18: Frequency and Direction of Winter (December, January, February) Winds Measured at Port Mellon Meteorological Station from 1997 to 2001. (The total length of each 'petal' is indicative of the relative frequency of occurrence of winds *from* that direction; for a given wind direction, each colour represents the relative proportion of wind speed ranges.)

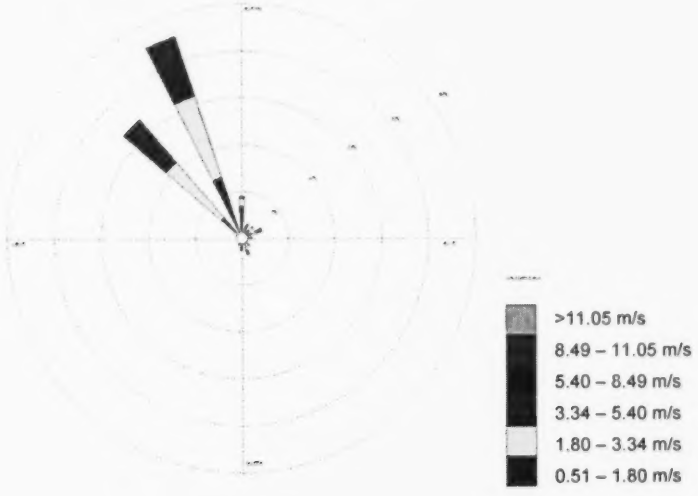


Figure 4.19: Frequency and Direction of Summer (June, July, August) Daytime (7am to 5pm) Winds Measured at Port Mellon Meteorological Station from 1997 to 2001. (The total length of each 'petal' is indicative of the relative frequency of occurrence of winds *from* that direction; for a given wind direction, each colour represents the relative proportion of wind speed ranges.)

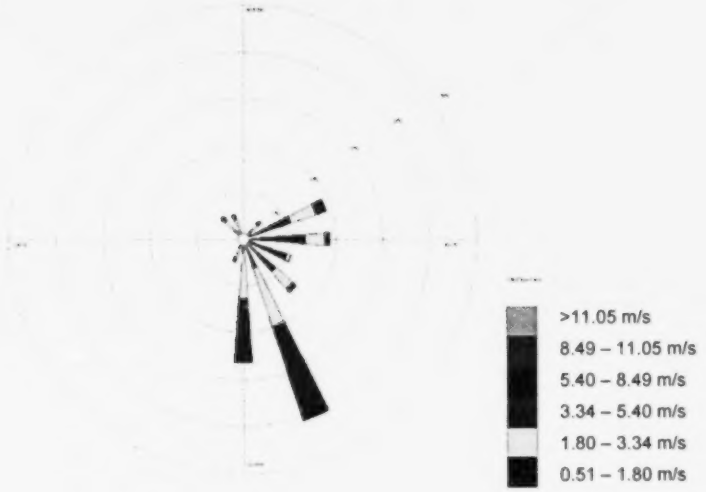
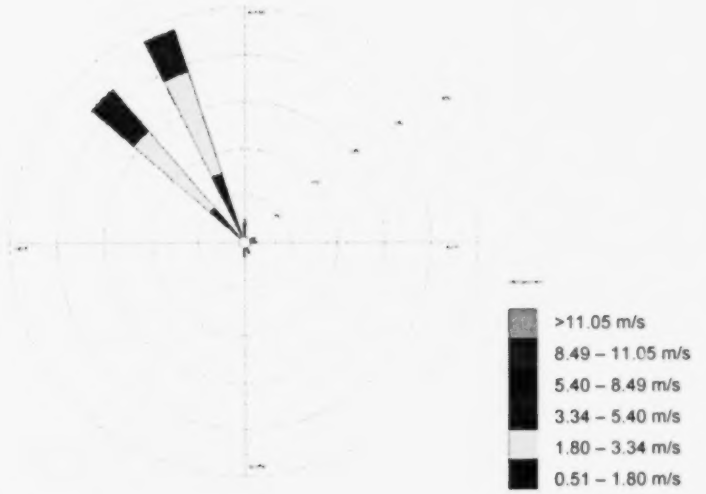


Figure 4.20: Frequency and Direction of Summer (June, July, August) Night time (Midnight to 7am) Winds Measured at Port Mellon Meteorological Station from 1997 to 2001. (The total length of each 'petal' is indicative of the relative frequency of occurrence of winds *from* that direction; for a given wind direction, each colour represents the relative proportion of wind speed ranges.)



Northwesterly winds dominate in the winter at Port Mellon Meteorological Station. These winds are most likely attributable to outflow winds from the surrounding valleys on the western shores of Howe Sound. Figure 4.18 shows the wind rose for the winter months (December, January, February) for the years 1997 to 2001. While there are occasional winds from the south during this winter period, these are most likely attributable to passing fronts and are generally short-lived.

As shown in Figure 4.17, winds in Langdale can also blow from the south, but this generally occurs during the summer months. In the summer, daytime heating of the mountain slopes around Howe Sound draws air up into the sound and the surrounding mountains. The southerly summer daytime (10am to 7pm) winds in Figure 4.19 are much faster (see colour legend) than the westerly and northwesterly outflow and night time winds. A wind rose showing the night-time (midnight to 7am) summer (June to August) winds from 1997 to 2001 is presented in Figure 4.20. This figure, when grouped with figure 4.19, gives a comprehensive picture of the summertime land-sea breeze that occurs in Port Mellon.

4.4.2 Temperature

Temperature data for the Port Mellon station was analyzed for the period May 1997 to December 2001. Table 4.15 summarizes the annual percent data capture, the annual minimum and maximum temperatures, and the annual temperature mean and standard deviation. Minimum and maximum temperatures are reported as the individual lowest and highest temperature readings taken over a 1-year period, and the annual mean and standard deviation are reported as the arithmetic mean and standard deviation of the 12 monthly mean values for that year (according to WMO Technical Regulation 4.2.4).

Please note that the *mean temperatures in this report are computed as the arithmetic mean* and the standard deviation is reported as the root-mean-square of the deviations from the arithmetic mean. *The mean daily temperatures reported in many climatological normals (including Environment Canada meteorological stations) are given by the average of the daily maximum and minimum temperatures.* Thus an additional mean is given for WLAP stations called the "thermometer mean daily temperature" which is the average of the daily maximum and minimum temperatures that would normally be calculated for a station equipped with only a max-min thermometer. These "thermometer means" may be used to compare directly with climatological normals computed at non-automated stations and those of Environment Canada. WMO recommends calculation of an arithmetic mean when 24-hour data is available (Section 5.2.4.1.1), which has been done in this report. This calculation also provides a more reliable method for assessing trends related to longer term averages such as climate change.

Table 4.15: Percentage of Valid Data Captured, Annual Minimum and Maximum Temperatures, and Annual Temperature Mean and Standard Deviation for Each Year Measured at Port Mellon Meteorological Station from 1997 to 2001.

Year	% Data Capture	Minimum (°C)	Maximum (°C)	Mean (°C)	Std Dev (°C)
1997	52.0	n/a	28.72	n/a	n/a
1998	100.0	-7.36	30.95	11.46	5.74
1999	99.95	0.54	26.87	10.14	4.95
2000	100.0	-2.21	28.96	10.26	5.24
2001	100.0	-0.99	28.79	10.33	4.99

For the averaging period 1997 to 2001, the climatological statistics are presented in Table 4.16. While this averaging period is only 5 years, these statistics nonetheless provide a reasonable history for comparative purposes. The data were processed according to WMO standards for missing data.

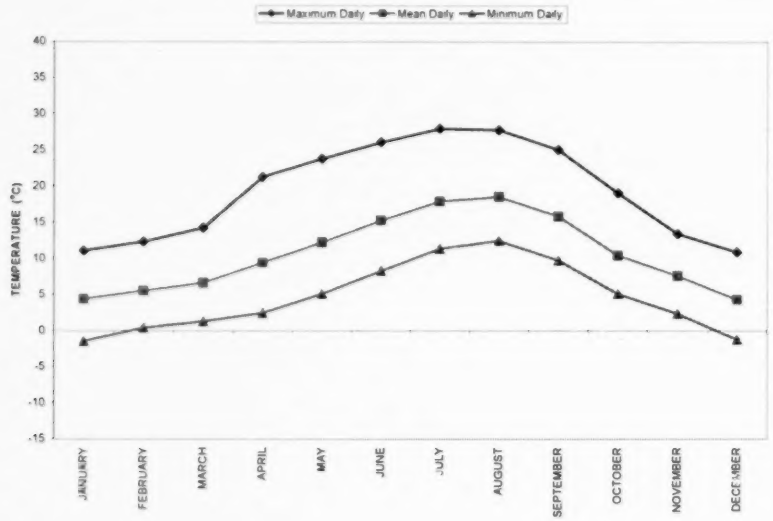
On average, the difference between the thermometer mean and arithmetic mean daily temperatures is 1.4 °C, with the maximum differences occurring in the warmer months (+2.4 °C) and the minimum differences occurring in the colder months (0.3 °C).

The data presented in tabular form in Table 4.16 is also presented graphically in Figure 4.21. Note that the arithmetic mean is used in this graph. In general, the mean daily temperatures in Port Mellon remain above freezing (0°C) year-round. Minimum temperatures are below freezing for the winter months (November through March), and above freezing for the remainder of the year. These mild temperatures can be attributed to the moderating influences of the surrounding ocean.

Table 4.16: Provisional Climatological Temperature Normals (1997 to 2001) for Port Mellon Meteorological Station.

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Arithmetic Mean Daily Temperature (°C)	4.4	5.5	6.5	9.4	12.2	15.2	17.8	18.5	15.8	10.4	7.5	4.2
Standard Deviation (°C)	2.4	2.2	2.5	3.5	3.5	3.4	3.2	3.1	3.0	2.4	2.4	2.5
Maximum Daily Temperature (°C)	11.0	12.3	14.2	21.2	23.7	26.0	27.9	27.7	25.0	19.0	13.4	10.8
Minimum Daily Temperature (°C)	-1.5	0.4	1.2	2.4	5.0	8.2	11.3	12.4	9.7	5.0	2.3	-1.3
Thermometer Mean Daily Temperature (°C)	4.7	6.3	7.7	11.8	14.4	17.1	19.6	20.1	17.3	12.0	7.8	4.8

Figure 4.21: Maximum, Minimum and Mean Daily Temperatures Measured At Port Mellon Meteorological Station for the years 1997 to 2001.



4.5 Western Pulp (Woodfibre)

A meteorological station was installed at Western Pulp (Woodfibre) in 1997 and continues to operate for the purpose of collecting data for dispersion modelling purposes only. Like Port Mellon, this station is not Ministry standard. The equipment at Western Pulp is not routinely calibrated, and is therefore considered less reliable. The data can be made available by calling the Lower Mainland office at (604) 582-5200.

4.6 Sea-to-Sky Regional Climatological Summary

Meteorological Data is only collected in the southern, or Lower Sea-to-Sky portion of the airshed by the Ministry of Water, Land and Air Protection (Environment Canada, however, operates stations in Squamish, Whistler and Pemberton). Therefore this summary will focus on the climatology of the Howe Sound area only.

In general, winds in Howe Sound are either northerly or southerly, but individual coastal locations can experience some easterly or westerly components if located at the mouth of an east/west mountain valley. In all seasons except the summer, winds generally flow from north to south, and in summer a land-sea breeze cycle tends to dominate, with southerly winds in the daytime, and northerly winds at night. A picture of the annual average wind conditions at each of the meteorological station locations is provided in Figure 4.22.

Figure 4.22: Annual Wind Conditions (given by wind roses – for scale/colour interpretation see Figure 4.20) for the Lower Sea-to-Sky Region Meteorological Stations. From North to South, the Stations are Squamish, Port Mellon, and Langdale.

In winter, the winds in Howe Sound are usually related to larger-scale weather patterns in British Columbia (outflow winds that occur when a ridge of high pressure dominates over the interior region of British Columbia), although topography does play a role in influencing these winds. In general, the winter time synoptic-scale winds are almost always northerly, but these get altered somewhat as they move down Howe Sound. In Squamish, winter winds are most often from the northeast, and flow into Howe Sound. As the winds flow to the south, they are diverted around Anvil, Gambier and Bowen Island. Most of the time, the strongest windflow is directed down the eastern side of Howe Sound[4]. On the western coast at Port Mellon and Langdale, winds in winter tend to be from the northwest (influenced more by outflow winds from northwestern mountain valleys). Average temperatures at all of these locations during the winter months remain between 2 and 10°C, while minimum temperatures drop to no more than 2 degrees below zero, and maximum winter temperatures can reach 15°C.

The driving force influencing wind directions changes more frequently in the transitional months (spring and fall) than in other seasons. During these months, warm spells can bring about land-sea/sea-land breezes, but most of the time winds continue to follow the winter patterns. A detailed discussion regarding the winds under different synoptic-scale weather systems is outlined in *Lange, 1998*[4]. In the spring (March, April, May), average temperatures are between 5 and 15°C while minimum temperatures are consistently above zero. Maximum temperatures can range from 15°C in March to 25°C in May. In the fall, the minimum and average temperatures are slightly higher than in the spring (by 2 or 3 degrees), while the maximum temperatures are in approximately the same range.

In summer, land-sea breezes influence the wind conditions in the Lower Sea-to-Sky Airshed. In the summer, daytime heating of the mountain slopes around Howe Sound draws air up into the mountains (a reversal of the winter situation). This air is drawn up into the mountains in a cumulative process, such that winds gain more speed as they approach Squamish at the head of Howe Sound[4]. This explains why the southwesterly winds are much faster than the northeasterly outflow winds at Squamish. On the western shores of Howe Sound in areas like Port Mellon and Langdale, the land/sea breeze tends to be more easterly during the day and westerly in the evening. It would presumably be the opposite on the eastern shores of Howe Sound although there is limited meteorological data available with which to validate this theory. Temperatures in the summer months (June, July, August) average around 16°C (average between daytime and nighttime temperatures) with daytime maximums reaching between 25 and 30°C. Minimum summer temperatures in the region are typically between 5 and 10°C.

5.0 POLLUTANTS MEASURED BY CONTINUOUS MONITORS

5.1 SO_2 – Sulphur Dioxide

5.1.1 Characteristics

Sulphur dioxide (SO_2) belongs to a family of sulphur oxide gases (SO_x) and is released into the atmosphere through the combustion of sulphur-containing fossil fuels (mainly coal and oil) and other industrial processes. It is a colourless gas, but is an irritant, with a perceptible odour at high concentrations (> 1000 $\mu g/m^3$)[4]. Both human health and the environment can be adversely affected by SO_2. SO_2 can be transported for long distances and can be converted to sulphate particles which may reduce visibility and affect human health (in the form of $PM_{2.5}$), or be converted to acidic particles which can contribute to the phenomenon known as acid rain. Exposure to SO_2 and its byproducts can affect breathing and respiratory illnesses, and can aggravate existing cardiovascular disease[6].

5.1.2 Sources

The major sources of SO_2 in the Sea-to-Sky Airshed are point (stack) sources - primarily the paper and allied product industry (approximately 70% of total SO_2 emissions in the airshed), as well as some mobile sources (marine vessels). These emissions are low relative to those in towns and cities of a similar size in the eastern part of the continent, mainly because of the relatively modest use of coal or oil as a heating or industrial fuel in the Pacific Northwest.

5.1.3 Air Quality Objectives

The BC provincial air quality objectives for sulphur dioxide (SO_2) in British Columbia are similar to the federal air quality objectives. These are based on a 1 hour, 24 hour and annual averaging period, and are presented in Table 5.1. For an explanation of the BC and National objectives and their definitions, see section 3.0.

Table 5.1: Provincial and National Air Quality Objectives for Sulphur Dioxide (SO_2).

Averaging Period	BC Level A ($\mu g/m^3$)	BC Level B ($\mu g/m^3$)	BC Level C ($\mu g/m^3$)	Maximum Desirable ($\mu g/m^3$)	Maximum Acceptable ($\mu g/m^3$)	Maximum Tolerable ($\mu g/m^3$)
1 hour	450	900	900-1300	450	900	
24 hour	160	260	360	150	300	800
Annual	25	50	80	30	60	

5.1.4 Monitoring Results

Sulphur dioxide (SO_2) is currently measured at two stations in the Sea-to-Sky Airshed (Squamish and Langdale), and was measured briefly for one and a half years in Gibsons. The mean sulphur dioxide concentrations are at very low levels at all three sites, and are well below the air quality objectives listed in Table 5.1. Since monitoring began in the early 1990s, there have been zero exceedances of the strictest SO_2 air quality objectives for any averaging period.

<u>Squamish</u>

Sulphur dioxide has been measured in Squamish at Ambient Air Station 0310172 since 1993. SO_2 is monitored at this station using a TECO 43A analyzer. The station is located at the Provincial Government Building at 30875 2nd Ave. A summary of the station location and details is given in Table 5.2. Photographs of the station are provided in Appendix A.

In most cases, the SO_2 concentrations in Squamish approximate 10% of the strictest air quality objective. A summary of SO_2 concentrations measured in Squamish from 1993 to 2001 is presented in Table 5.3,

and the equivalent data is presented in graphical form in Figure 5.1. These values are similar to SO_2 concentrations measured in the Greater Vancouver Regional District with the exception of North Burnaby which is influenced by emissions from a nearby oil refinery. While it appears that there is a significant change in annual average concentrations between 1996 and 1997, this difference is due to a higher incidence of low-level concentrations (3 $\mu g/m^3$) over an extended period of time in the late-1990s and not any change in detection limits or instrumentation.

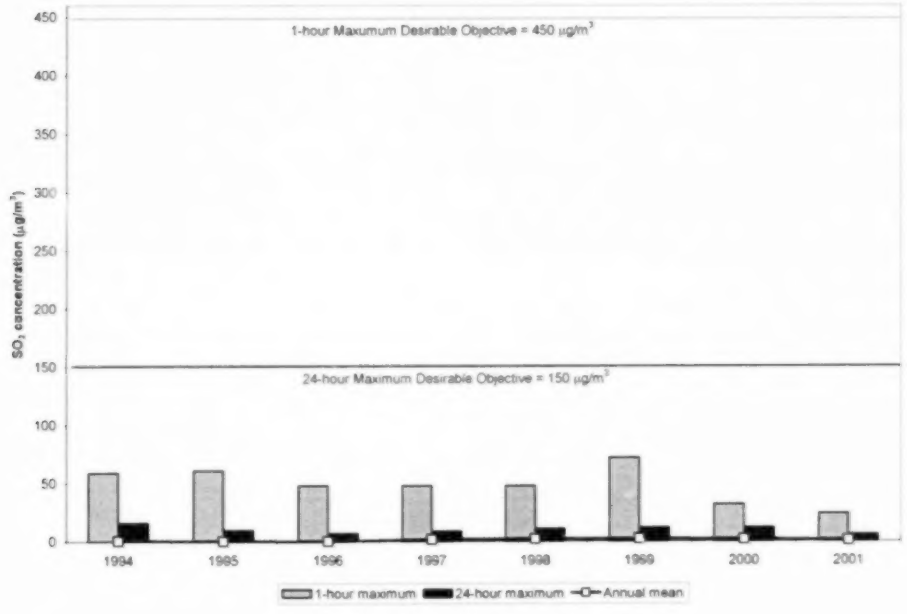
Table 5.2 Summary of Station Details for Squamish Ambient Air Station.

Station Code	Address	Lat / Long	UTM (NAD 83)	Elevation	Intake ht. (above ground)
0310172	30875 2nd Ave. Squamish, BC	49° 41' 59" N 123° 09' 16" W	Zone 10 488879.6 5505278.7	10 m	13 m

Table 5.3: Annual Summary of Sulphur Dioxide (SO_2) Concentrations Measured in Squamish from 1993 to 2001.

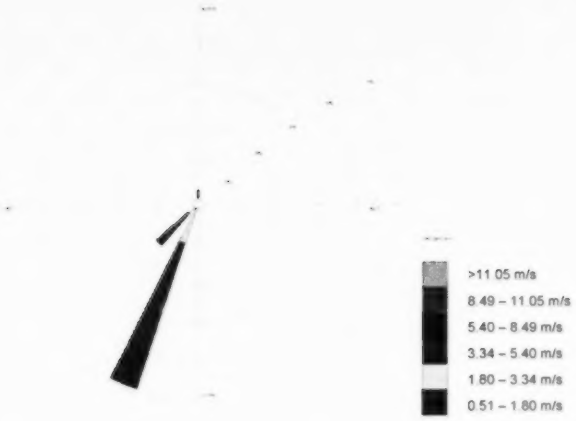
Year	% Data Capture	Annual Average SO_2 Concentration ($\mu g/m^3$)	Maximum 1-hour SO_2 Concentration ($\mu g/m^3$)	Maximum 24-hour SO_2 Concentration ($\mu g/m^3$)
1993	39.5	n/a	45	7
1994	89.9	0.5	59	16
1995	93.8	0.3	61	10
1996	95.7	0.2	48	7
1997	95.7	1.8	48	9
1998	95.7	2.3	48	11
1999	94.5	2.4	72	12
2000	91.2	1.9	32	12
2001	93.9	1.0	24	6

Figure 5.1: Summary of Sulphur Dioxide (SO_2) Concentrations Measured in Squamish from 1994 to 2001 (1993 was excluded because of low data capture).



Winds associated with higher 1-hour SO_2 concentrations are shown in a pollution rose in Figure 5.2. The pollution rose includes only the wind data from those hours where the 1-hour SO_2 concentrations are equal to or higher than 45 $\mu g/m^3$ (10% of the 1-hour BC Level A Objective of 450 $\mu g/m^3$). The threshold of 45 $\mu g/m^3$ was chosen for this pollution rose because of the large number of low-concentration days experienced at this location. The wind rose shows that winds from the south-southwest carry the highest SO_2 concentrations – these winds are from the Howe Sound region, where the largest sources (pulp and paper mills) of sulphur dioxide are located.

Figure 5.2: Frequency and Direction of Winds Associated with SO_2 Concentrations Equal to or Higher than 45 $\mu g/m^3$ Measured in Squamish from 1993 to 2001. (The total length of each 'petal' is indicative of the relative frequency of occurrence of winds *from* that direction; for a given wind direction, each colour represents the relative proportion of wind speed ranges.)



Langdale

Sulphur dioxide has been measured in Langdale since December 1995 at the Langdale Elementary School at the corner of Johnson and Forbes Road. SO_2 concentrations at this station are also measured with a TECO 43A analyzer. Photographs of the station can be found in Appendix A.

Table 5.4 Summary of Station Details for Langdale Elementary Ambient Air Station.

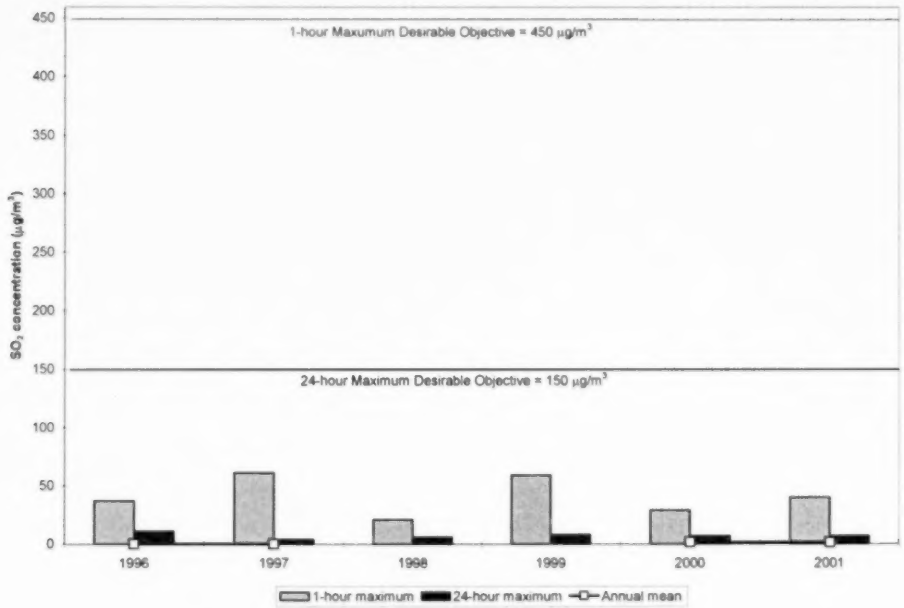
Station Code	Address	Lat / Long	UTM (NAD 83)	Elevation	Intake ht. (above ground)
E222778	1551 Forbes Rd.	49° 26' 20" N 123° 28' 45" W	Zone 10 465266 E 5476374 N	82 m	3.5 m

The SO_2 concentrations in Langdale are on average even lower than those measured in Squamish, and are therefore also well below air quality objectives. The SO_2 concentrations measured in Langdale from 1996 to 2001 are shown in Table 5.5 and presented graphically in Figure 5.3.

Table 5.5: Annual Summary of Sulphur Dioxide (SO_2) Concentrations Measured in Langdale from 1996 to 2001.

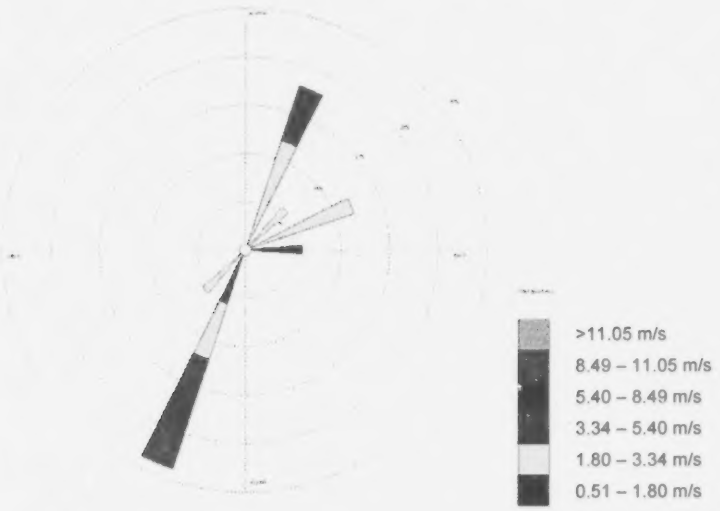
Year	% Data Capture	Annual Average SO_2 Concentration ($\mu g/m^3$)	Maximum 1-hour SO_2 Concentration ($\mu g/m^3$)	Maximum 24-hour SO_2 Concentration ($\mu g/m^3$)
1996	94.8	0.1	37	11
1997	94.6	0.3	61	4
1998	47.6	n/a	21	6
1999	64.5	n/a	59	8
2000	94.8	1.6	29	7
2001	93.3	1.4	40	7

Figure 5.3: Summary of Sulphur Dioxide (SO_2) Concentrations Measured in Langdale from 1996 to 2001.



The pollution wind rose for SO_2 in Langdale is shown in Figure 5.4. This wind rose shows only wind data for those hours where 1-hour SO_2 concentrations are greater than 20 $\mu g/m^3$ (which is different from the previous wind rose for Squamish which uses a threshold of 45 $\mu g/m^3$). A lower threshold for this pollution rose was chosen than that for Squamish because of the very limited data set. As there is only wind data available for 1996 and 1997, the pollution wind rose is limited to 12 individual hours of wind data. What is significant in this figure is the apparent duality in SO_2 sources. All of the hours included in the pollution rose were found to be daytime hours (9am to 6pm). The SO_2 from the northeast is presumably from the pulp and paper industries to the northeast in Howe Sound, and occur between the hours of 9am and 2pm. The SO_2 from the south-southwest occurs later in the day (between 3pm and 6pm) and may be due to a reversal of winds and a re-direction of the plume, or it may be from other sources such as marine vessels. This graph should be evaluated with caution, as it represents a very limited amount of data at a relatively low threshold (20 $\mu g/m^3$). The re-installation of a meteorological station in Langdale (planned for 2004) will help to increase this data set and may improve the assessment of the SO_2 pollution-source relationship in Langdale.

Figure 5.4: Frequency and Direction of Winds Associated with SO_2 Concentrations Equal to or Higher than 20 $\mu g/m^3$ Measured in Langdale from 1996 to 2001. (The total length of each 'petal' is indicative of the relative frequency of occurrence of winds *from* that direction; for a given wind direction, each colour represents the relative proportion of wind speed ranges.)



Gibsons

Sulphur dioxide was measured briefly in Gibsons at the Townhall site between 1993 and 1994. A summary of the station details is provided in Table 5.6. Photographs of the Townhall are provided in Appendix A. Exact measurements of the intake height are not available, but are based on approximate heights derived from photographs.

Table 5.6: Summary of Station Details for Gibsons Townhall Ambient Air Station.

Station Code	Address	Lat / Long	UTM (NAD 83)	Elevation (ASL)	Intake ht. (above ground)
E217062	474 S. Fletcher Road	49° 24' 1" 123° 30' 34"	Zone 10 463049 E 5472039 N	25	~ 5 m

SO_2 data was collected in Gibsons from April 1993 to December 1994, although there is no meteorological data to compliment the air quality evaluation. SO_2 levels are similar to those measured in Langdale and Squamish. The 1-hour, 24-hour and annual concentrations are all well below air quality objectives for SO_2 for the measurement period, as shown in Table 5.7. Although data is limited, it appears that SO_2 concentrations in the Sea-to-Sky Airshed are highest in Squamish, compared with those on the southwestern shores of Howe Sound (Langdale and Gibsons). The higher 1-hour SO_2 concentrations are episodic in nature and are most likely related to industrial processes at the pulp mills in the region. The longer-term average conditions, in turn, are therefore very low.

Table 5.7: Annual Summary of Sulphur Dioxide (SO_2) Concentrations Measured in Gibsons in 1993 and 1994.

Year	% Data Capture	Annual Average SO_2 Concentration ($\mu g/m^3$)	Maximum 1-hour SO_2 Concentration ($\mu g/m^3$)	Maximum 24-hour SO_2 Concentration ($\mu g/m^3$)
1993	66.4	n/a	35	6
1994	85.6	0.12	27	5

5.2 Total Reduced Sulphur (TRS) /Hydrogen Sulphide (H_2S)

5.2.1 Characteristics

Total reduced sulphur (TRS) refers to a group of sulphurous compounds, made up primarily of dimethyl disulphide (DMDS), dimethyl sulphide (DMS), methyl mercaptan (MESH), and hydrogen sulphide (H_2S). These compounds are emitted as byproducts from industrial sources such as pulp and paper mills and petroleum refineries, as well as from natural sources such as swamps and marshes.

TRS is considered a nuisance pollutant because at low concentrations it has a "rotten egg" odour. Health effects from TRS are not well researched, but it appears that those who live nearby TRS sources have significantly more coughs and headaches as well as respiratory infections than in reference communities where TRS sources are not prevalent[6].

5.2.2 Sources

The most significant anthropogenic sources of TRS in the Sea-to-Sky Airshed are pulp and paper mills. There is one pulp and paper mill located on the northwestern shore of Howe Sound (Woodfibre) close to Squamish, and another located at Port Mellon on the southwestern shore of Howe Sound, closer to Langdale.

5.2.3 Air Quality Objectives

The BC provincial air quality objectives for total reduced sulphur (TRS) in British Columbia are based on 1 hour and 24 hour averaging periods and are presented in Table 5.8. Air quality objectives also exist for Hydrogen Sulphide (H_2S), one of the reduced sulphur compounds with a recognizable odour. Both the National and Provincial objectives for H_2S are similar to those for TRS. For an explanation of the BC and National objectives and their definitions, see section 3.0.

Table 5.8: Provincial and National Air Quality Objectives for Total Reduced Sulphur (TRS) and Hydrogen Sulphide (H_2S).

Pollutant	Averaging Period	BC Level A ($\mu g/m^3$)	BC Level B ($\mu g/m^3$)	BC Level C ($\mu g/m^3$)	Maximum Desirable ($\mu g/m^3$)	Maximum Acceptable ($\mu g/m^3$)	Maximum Tolerable ($\mu g/m^3$)
TRS	1 hour	7	28				
	24 hour	3	6				
H_2S	1 hour	7.5-14	28-45	42-45	1	15	
	24 hour	4	6-7.5	7.5-8		5	

5.2.4 Monitoring Results

Monitoring of TRS occurs presently in Squamish and Langdale, and was measured for brief periods in other areas of Langdale, Gibsons, Horseshoe Bay, Gambier Island, and Porteau Cove. TRS instrumentation and programming protocol was changed in 1990/1991 and may account for the significant change in TRS concentrations at this period in time (this trend does not reflect any change in emissions or control technology). In all tables presented in this section, a column is given which indicates the lowest detectable limit for TRS (either 0, 3 or 7 $\mu g/m^3$), so that appropriate comparisons can be drawn between stations or from year to year. It should also be noted that for those years in which the lowest detectable limit was above air quality objective levels (e.g. if the lowest detectable limit is 7 $\mu g/m^3$ and the 24-hour average objective is 3 $\mu g/m^3$), "n/a" is indicated in the column under that particular objective to indicate that it was not applicable.

Squamish

Monitoring of TRS began in Squamish in 1985 and continues to present day. The station description for the Squamish Ambient Air Station can be found in Table 5.2.

The original TRS instrumentation installed in Squamish was a Philips PW9700 SO_2 analyzer with a thermal oxidizer, which was replaced with a TECO 43A analyzer plus thermal oxidizer in the early 1990s.

A summary of the measured TRS concentrations in Squamish from 1985 to 2001 is presented in Table 5.9, and is presented graphically for the years 1991 to 2001 in Figure 5.5. In the mid to late 1980s, 1-hour TRS concentrations were considerably higher than they were in the following decade. It is not known whether changes in industrial emissions or measurement protocol, or a combination of both factors are responsible for this significant difference. In the past decade (1990s), the BC Level A Objective for TRS was exceeded for at least one hour every year, although in the worst case since 1990, this objective was exceeded no more than 0.2 % of the time (in 1994).

Table 5.9: Annual Summary of Total Reduced Sulphur (TRS) Concentrations Measured in Squamish from 1985 to 2001.

Year	Detection Limit	% Data Capture	Annual Average TRS Conc. ($\mu g/m^3$)	Max. 1-hour TRS Conc. ($\mu g/m^3$)	No. of 1-hour Values		Maximum 24-hour TRS Conc. ($\mu g/m^3$)	No. of daily (24-hour) Values	
					> 7 $\mu g/m^3$	> 28 $\mu g/m^3$		> 3 $\mu g/m^3$	> 6 $\mu g/m^3$
1985	7	68.3	n/a	135	123	13	20	n/a	n/a
1986	7	69.7	n/a	42	20	1	13	n/a	n/a
1987	7	90.8	7.0	14	10	0	7	n/a	n/a
1988	7	82.4	7.0	21	4	0	9	n/a	n/a
1989	7	28.1	n/a	7	n/a	n/a	7	n/a	n/a
1990	3 / 0	68.2	n/a	10	3	0	4	n/a	0
1991	0	95.4	0.1	14	7	0	3	0	0
1992	0	95.3	0.1	17	3	0	2	0	0
1993	0	65.6	n/a	11	1	0	1	0	0
1994	0	80.8	0.1	13	10	0	3	1 (20)	0
1995	0	92.0	< 0.1	11	3	0	1	0	0
1996	0	93.5	0.1	10	2	0	3	0	0
1997	0	94.8	0.4	9	6	0	3	0	0
1998	0	94.2	0.3	13	11	0	2	0	0
1999	0	94.6	0.6	7	1	0	3	0	0
2000	0	91.1	0.3	9	2	0	2	0	0
2001	0	93.8	0.2	10	2	0	2	0	0

Due to the episodic nature of TRS concentrations and their relationship to industrial activities, it is difficult to associate a trend to this data. There appears to be, however, a general downward trend in the maximum 1-hour concentration (perhaps fewer episodes at mills), but this downward trend is not seen in the longer-term average concentrations of TRS in Squamish (Figure 5.5).

A pollution wind rose showing the frequency of wind speeds and directions during hours of high TRS concentrations in Squamish is shown in Figure 5.6. This pollution rose shows only wind data for those hours where the BC Level A objective is exceeded (does not include data earlier than 1991 because of incompatibility between objectives and detection limits). This wind rose looks similar to that for the SO_2 concentrations for Squamish, whereby the highest concentrations occur when winds are from the southwest where the pulp mill source is located.

Figure 5.5: 1-hour Maximum, 24-hour Maximum, and Annual Average TRS concentrations for the years 1991-2001 in Squamish.

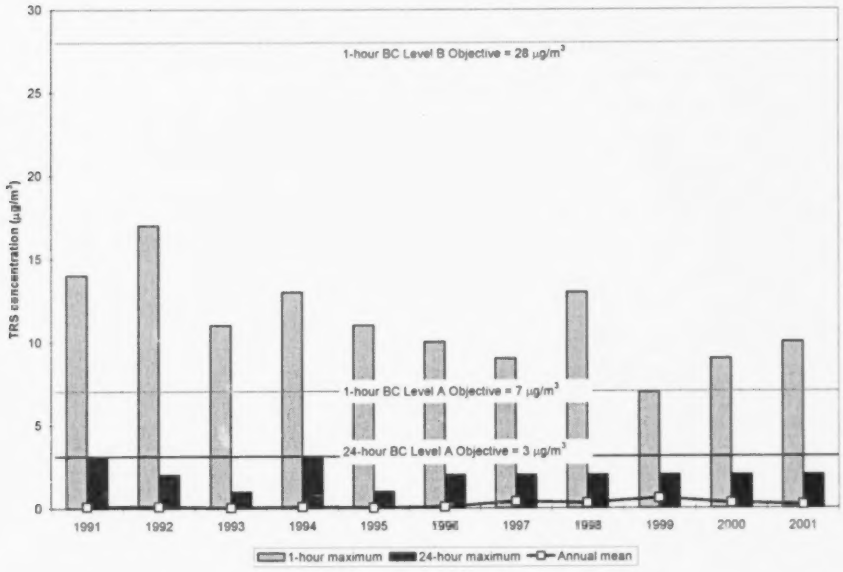


Figure 5.6: Frequency and Direction of Winds Associated with TRS Concentrations Equal to or Higher than the BC Level A Objective of 7 µg/m^3 Measured in Squamish from 1991 to 2001. (The total length of each 'petal' is indicative of the relative frequency of occurrence of winds *from* that direction; for a given wind direction, each colour represents the relative proportion of wind speed ranges.)

Lower Sea-to-Sky Region

Significant TRS sampling was done in the mid-1980s to mid-1990s in the Lower Sea-to-Sky Airshed near the major emission sources in Howe Sound (pulp mills). These measurements were done in various locations around Horseshoe Bay, Porteau Cove, Langdale, Gibsons and Gambier Island. A summary of the measurement results at these various sites is given in Table 5.10. Most of these measurements were done for short periods of time, as monitors were moved to different locations around Howe Sound regularly to capture different receptor concentrations.

In Horseshoe Bay, measurements were conducted from 1984 to 1990 at the West Vancouver Firehall No. 2 located at 6645 Nelson; at a private residence on Madrona Cr.; at Libby Lodge at 6510 Marine Dr.; at the Horseshoe Bay Ferry Terminal, and at a private residence on Isleview Dr. Details about each of the stations (where available) are given in Appendix A.

Concentrations of TRS in Horseshoe Bay were very low during the various measurement periods, and only exceeded the 1-hour Maximum BC Level A Objective in 1984 and 1985 to a maximum of 10 hours per year (0.1% of the time). With the exception of 1987, data capture at these locations was limited, and may not present a thorough picture. However, it can be stated that these concentrations are significantly lower than those observed in Squamish during the same measurement period.

Concentrations of TRS in Porteau Cove were monitored in 1987 and from 1990 to 1993. In general, concentrations also remained low here for most hours of the year, although the highest recorded 1-hour TRS level in Porteau Cove (40 $\mu g/m^3$) occurred in 1990. This same event (September 6, 1990) was not captured at Squamish. Winds measured in Squamish during that period were from the northeast, indicating that outflow winds were occurring at that time, directing air out of Howe Sound and into Georgia Strait. In summary, TRS concentrations at Porteau Cove were generally lower than those measured in Squamish, although different TRS events were captured at the two stations depending on Howe Sound wind flow conditions.

TRS concentrations measured at the Langdale YMCA/Camp Elphinstone station in the early 1990s were among the highest in the airshed. These concentrations were higher, in fact, than those measured nearby at Langdale Elementary School, although these were not taken concurrently. The school location is considerably further inland compared with the YMCA site, which may be capturing more of the pulp mill emissions over or near the water.

Table 5.10: Annual Summary of Total Reduced Sulphur (TRS) Concentrations Measured between 1984 and 1997 in the Lower Sea-to-Sky Airshed.

Year	Station Name	Det. Limit	% Data Capture	Annual Average TRS Conc. ($\mu g/m^3$)	Max. 1-hour TRS Conc. ($\mu g/m^3$)	No. of Hourly Values > 7 $\mu g/m^3$	Maximum 24-hour TRS Conc. ($\mu g/m^3$)	No. of Daily (24 hr) Values > 3 $\mu g/m^3$
1984	Horseshoe Bay – Firehall	7	1.5	n/a	7	0	7	n/a
1985	Horseshoe Bay-Firehall	7	37.1	n/a	21	10	8.5	n/a
	Horseshoe Bay – Madrona Cr.	7	21.7	n/a	14	2	7.6	n/a
1986	Horseshoe Bay – Madrona Cr.	7	27.2	n/a	14	4	7.3	n/a
	Horseshoe Bay – Libby Lodge	7	10.2	n/a	7	0	7	n/a
	Horseshoe Bay – Ferry Terminal	7	8.9	n/a	7	0	7	n/a
1987	Horseshoe Bay – Ferry Terminal	7	93.7	7	7	0	7	n/a
	Porteau Cove	7	45.7	n/a	7	0	7	n/a
1988	Horseshoe Bay – Ferry Terminal	7	8.1	n/a	7	0	7	n/a
1989	n/a							
1990	Horseshoe Bay - Isleview Dr.	;/0	63.3	n/a	6	0	1.7	0
	Porteau Cove	3/0	51.8	n/a	40	3	5.6	n/a

	Langdale YMCA	0	62.5	1	27	37	4.8	11 (242)
1991	Horseshoe Bay – Isleview Dr.	0	7	n/a	4	0	0.9	0
	Porteau Cove	0	90.9	< 0.1	6	0	2.1	0
	Langdale YMCA	0	93.2	1	81	217 - 10	13.4	39 (914) – 5 (160)
1992	Porteau Cove	0	80.3	<0.1	4	0	0.8	0
	Langdale YMCA	0	87.5	0.9	23	65	8.6	14 (299) – 1 (23)
	Gibsons Firehall	0	58.8	n/a	14	14	5.7	6 (160)
1993	Porteau Cove	0	18.2	n/a	3	0	0.8	0
	Langdale YMCA	0	86.4	0.2	11	4	3.3	0 (14)
	Gibsons Firehall	0	84.0	0.2	8	1	3.6	2 (16)
	Gibsons Townhall	0	66.3	0.1	7	0	1.3	0
1994	Langdale YMCA	0	92.1	0.2	17	28	9.2	5 (89) – 0 (22)
	Gibsons Firehall	0	92.4	< 0.1	7	0	1.9	0
	Gibsons Townhall	0	84.4	< 0.1	8	2	5.1	1 (24)
1995	Langdale YMCA	0	83.2	0.1	10	5	3.2	0 (4)
	Gibsons Firehall	0	48.0	n/a	3	0	0.5	0
1996	Gambier Island	0	86.7	n/a	6	0	2.4	0
1997	Gambier Island	0	10.8	n/a	3	0	2.0	0

Langdale

A permanent monitoring site for measurement of TRS was installed at Langdale Elementary School in 1995. The station description for the Langdale Ambient Air Station can be found in Table 5.4 and photographs of the station can be found in Appendix A. The TRS instrumentation installed in Langdale is a TECO 43A SO_2 analyzer with a thermal oxidizer.

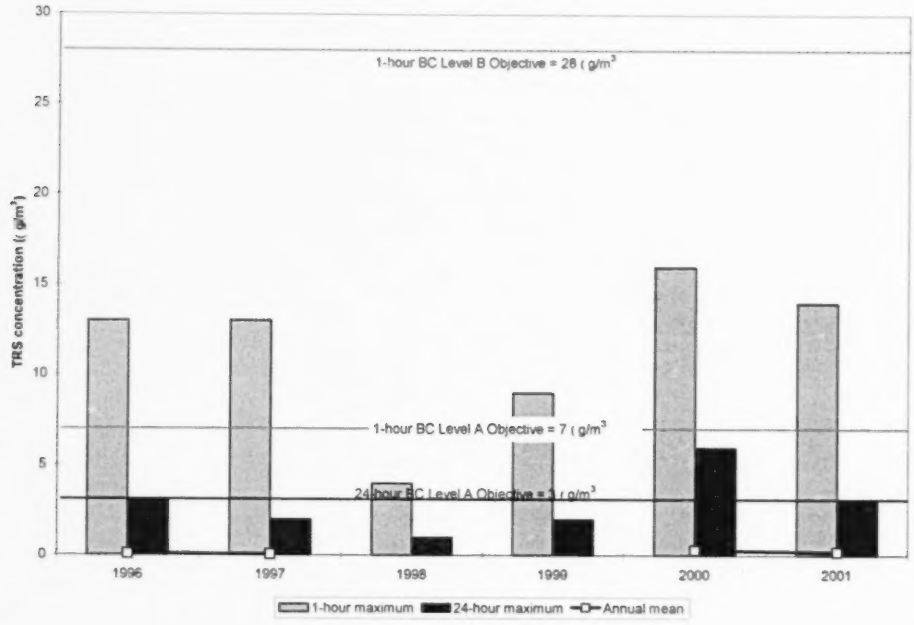
A summary of the 1-hour, 24-hour and annual TRS concentrations measured in Langdale between 1996 and 2001 is presented in Table 5.11 and graphically represented in Figure 5.7. The maximum 1-hour TRS concentrations exceed the BC Level A objective of 7 $\mu g/m^3$ in all years with the exception of 1998. In general, when compared with the Squamish station, Langdale experiences higher maximum concentrations and more frequent exceedances of the Level A Objective than does Squamish. However, annual averages are quite similar for both sites. No noticeable trend can be discerned from the Langdale TRS data.

Table 5.11: Annual Summary of Total Reduced Sulphur (TRS) Concentrations Measured in Langdale from 1996 to 2001.

Year	Detection Limit	% Data Capture	Annual Average TRS Conc. ($\mu g/m^3$)	Max. 1-hour TRS Conc. ($\mu g/m^3$)	No. of 1-hour Values		Maximum 24-hour TRS Conc. ($\mu g/m^3$)	No. of daily (24-hour) Values	
					> 7 $\mu g/m^3$	> 28 $\mu g/m^3$		> 3 $\mu g/m^3$	> 6 $\mu g/m^3$
1996	0	94.5	< 0.1	13	4	0	3	1 (15)	0
1997	0	94.6	< 0.1	13	4	0	2	0	0
1998	0	47.6	n/a	4	0	0	1	0	0
1999	0	64.4	n/a	9	2	0	2	0	0
2000	0	93.8	0.3	16	22	0	6	3 (62)	0
2001	0	95.6	0.2	14	10	0	3	0 (6)	0

Total reduced sulphur concentration levels are very episodic in nature and are therefore difficult to compare on an annual or 24-hour basis. In general, 1-hour maximum concentrations of TRS in Langdale are higher than those in Squamish, although at both stations the 1-hour BC Level A Objective is exceeded almost every year. The number of hours that the Level A Objective is exceeded is generally higher in Langdale (around 10-20 hours per year in recent years, or 0.1% to 0.2% of the time), but not consistently from year to year.

Figure 5.7: 1-hour Maximum, 24-hour Maximum, and Annual Average TRS concentrations for the years 1996 to 2001 in Langdale.



5.3 Nitrogen Dioxide (NO_2)

5.3.1 Characteristics

Nitrogen oxides of concern with respect to air quality are nitric oxide (NO) and nitrogen dioxide (NO_2). Both of these compounds are commonly referred to as NO_x. They are produced through the combustion of fossil fuels – NO is the predominant NO_x in combustion emissions, but rapidly undergoes chemical reactions in the atmosphere to form NO_2.

NO_x is a precursor for ground level ozone (O_3), secondary particulate matter (PM_{10} and $PM_{2.5}$), and acid rain formation. It is therefore a significant pollutant in that it directly and indirectly (as a precursor) contributes to impacts on human health and visibility. NO_2 is a reddish-brown gas that is most often associated with reduced lung function[6].

5.3.2 Sources

The most common sources of NO_x in the Sea-to-Sky Airshed are from internal combustion engines (from vehicles, rail and marine vessels). Transportation sources account for 56% of NO_x emissions, and stationary and area sources such as space heating account for the remaining 43.5% (Natural sources < 1%).

5.3.3 Objectives

Objectives are only available for NO_2 as it is the pollutant with the greatest health risks and is usually the most abundant ambient form of NO_x. There are no provincial objectives for nitrogen dioxide (NO_2) in British Columbia, although there are national air quality objectives. These are based on a 1 hour, 24 hour and annual averaging period, and are presented in Table 5.12. For an explanation of the national objectives and their definitions, please see section 3.0.

Table 5.12: National Air Quality Objectives for Nitrogen Dioxide (NO_2).

Averaging Period	Maximum Desirable ($\mu g/m^3$)	Maximum Acceptable ($\mu g/m^3$)	Maximum Tolerable ($\mu g/m^3$)
1 hour		400	1000
24 hour		200	300
Annual		100	

5.3.4 Monitoring Results

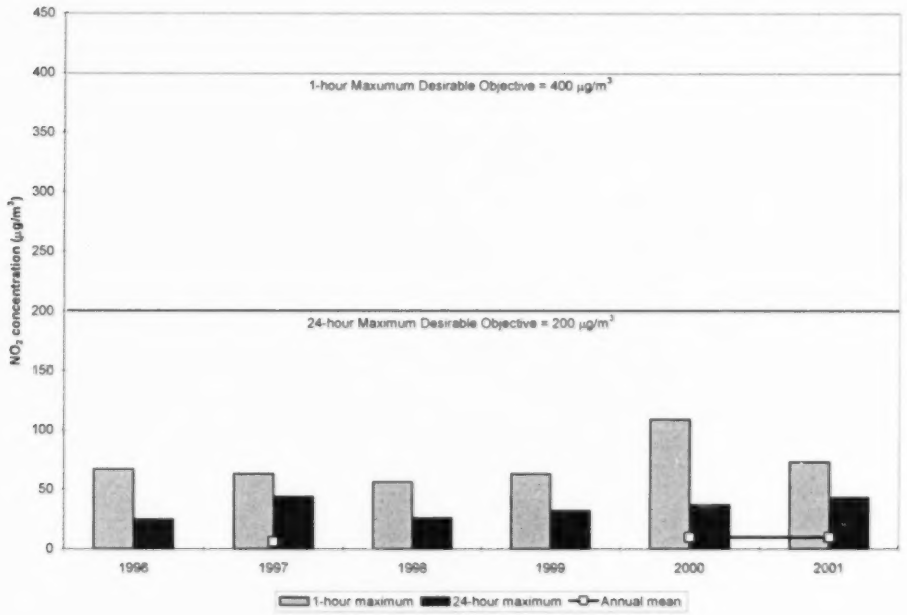
NO_x (NO_2 and NO) were only measured in Langdale within the Sea to Sky Airshed prior to 2002. NO_2 is reported in this document because of its human health effects and potential to form ozone (O_3). The NO_x monitor is an API 200 model located at the Langdale Elementary School station (details are provided in Table 6.4). Photographs of the station are located in Appendix A.

NO_2 concentrations at this location are well below federal acceptable levels. The highest reading since measurement began is approximately 25% of the federal standard. A summary of the 1-hour, 24-hour and annual concentrations of NO_2 for each year of monitoring in Langdale is presented in Table 5.13. A graphical representation of the data in Table 5.13 is shown in Figure 5.8. These document the relatively low NO_2 concentrations experienced on the southwestern shores of Howe Sound.

Table 5.13: Annual Summary of Nitrogen Dioxide (NO_2) Concentrations Measured in Langdale from 1996 to 2001.

Year	% Data Capture	Annual Average NO_2 Conc. ($\mu g/m^3$)	Max. 1-hour NO_2 Conc. ($\mu g/m^3$)	No. of Values > 400 $\mu g/m^3$	Maximum 24-hour (daily) NO_2 Conc. ($\mu g/m^3$)	No. of Values > 200 $\mu g/m^3$
1996	70.9	n/a	67	0	25 (25)	0
1997	94.3	6.2	63	0	44 (32)	0
1998	45.8	n/a	56	0	26 (25)	0
1999	64.5	n/a	63	0	32 (29)	0
2000	94.5	9.9	109	0	37 (30)	0
2001	95.4	9.8	73	0	43 (41)	0

Figure 5.8: 1-hour Maximum, 24-hour Maximum, and Annual Average NO_2 Concentrations for the Years 1996 to 2001 in Langdale.

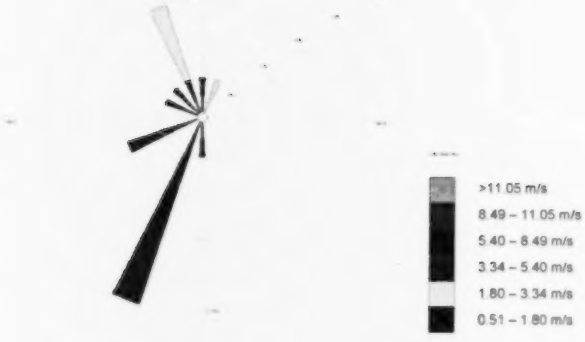


A pollution rose for those hours where the 1-hour NO_2 concentration in Langdale is greater than 50 $\mu g/m^3$ (this threshold was chosen due to the typically low concentrations of NO_2 at this location) is shown in Figure 5.9 (for 1996 and 1997 only, as there is no wind data after 1997). This figure indicates that the highest NO_2 concentrations occur when winds are calm or light and from the south-southwest and the north-northwest. While the data is very limited, there is an indication that the higher NO_2 concentrations, like the SO_2 concentrations, may occur from shifting winds or dual sources (such as marine vessels or vehicles and the pulp mill sources to the north). The re-activation of the Langdale meteorological station in 2004 may help shed more light on this NO_2 emission issue.

It appears that the annual average NO_2 concentrations since the mid-1990s have been increasing (from an annual average of 5 $\mu g/m^3$ to 9.8 $\mu g/m^3$), although adequate data is missing for the years 1998 and 1999 (See Figure 5.8). Further reviews of the NO_2 concentrations at this location will be needed to

support this potential trend. This would be reasonable, given the increasing population on the Sunshine Coast and associated vehicle emissions in the western Howe Sound region.

Figure 5.9: Frequency and Direction of Winds Associated with NO_2 Concentrations Equal to or Higher than 50 $\mu g/m^3$ Measured in Langdale from 1996 to 1997. (The total length of each 'petal' is indicative of the relative frequency of occurrence of winds *from* that direction; for a given wind direction, each colour represents the relative proportion of wind speed ranges.



5.4 Ozone

5.4.1 Characteristics

Ozone is a colourless, reactive gas that occurs naturally in the atmosphere. Ozone in the upper atmosphere (stratosphere) is critical to life on earth, as it protects biological systems from the damaging wavelengths of solar ultraviolet radiation. However, the physical and chemical properties that make ozone a critical component of the upper atmosphere are undesirable in high concentrations at ground level. Ozone is a powerful oxidant and it is significant to note that the powerful oxidizing properties of ozone have been put to use in the treatment of wastes, sterilization of equipment, bleaching of products, and purification of water.

Elevated ground-level ozone concentrations negatively impact on human health, vegetation, and property. Health impacts associated with ozone include irritation of the respiratory tract, aggravation of existing respiratory conditions (i.e. asthma, bronchitis, pulmonary emphysema), and eye irritation[6]. A threshold ozone concentration for which impacts to human health do not occur has not been identified and studies indicate a continuum of effects through all ambient levels of ozone.

Ozone (O_3) is a photochemical oxidant formed from nitrogen oxides (NO_x) and volatile organic compounds (VOCs) in the presence of sunlight. It is considered a 'secondary' pollutant because it is usually not discharged directly into the air, but is formed through chemical reactions between 'primary' (directly emitted) pollutants.

5.4.2 Sources

Because ozone is a secondary pollutant, it is necessary to look at the sources of its chemical precursors – NO_x and VOCs. In general, nitrogen oxides are emitted mainly from the transportation sector, while VOCs in the Sea to Sky airshed are emitted primarily from natural sources such as trees and other vegetation.

5.4.3 Objectives

There are no Provincial objectives for ground level ozone (O_3) in British Columbia, although there are National air quality objectives. These are based on a 1 hour, 24 hour and annual averaging period, and are presented in Table 5.14. For an explanation of the National objectives and their definitions, see section 3.0.

Table 5.14: National Air Quality Objectives for Ozone (O_3).

Averaging Period	Maximum Desirable ($\mu g/m^3$)	Maximum Acceptable ($\mu g/m^3$)	Maximum Tolerable ($\mu g/m^3$)
1 hour	100	160	300
24 hour	30	50	
Annual		30	

The Canada-Wide Standard (CWS) for Ozone is 65 ppb (8-hour average) based on the 4th highest measurement annually, averaged over three consecutive years. More details on the CWS can be found in Section 3.1.

5.4.4 Monitoring Results

Ozone is presently being monitored in Squamish and Whistler, and was previously measured for a short period of time in Pemberton from 1984 to 1986. The 1-hour ozone concentrations in the Sea to Sky Airshed are higher than might be anticipated (in relation to pollutants such as SO_2), and are, in fact, often equal to and sometimes higher than ozone levels measured in the Lower Fraser Valley. However, the

daytime maximum peaks in ozone in the Fraser Valley are usually higher than those measured in the Sea-to-Sky Airshed.

Pemberton

Between February 1985 and May 1986, B.C. Environment (now WLAP) collected 9982 hours of ground-level ozone sampling data in Pemberton. In that time, the National 1-hour "Maximum Desirable" Ozone Objective was exceeded 56 times during the period of June to August 1985. Station details are presented in Table 5.15, and photographs of the station can be found in Appendix A. The intake height was estimated from photographs of the station. Ozone was monitored using a Thermo Environmental Model 49 Ozone analyzer.

Table 5.15: Summary of Station Details for Pemberton Ambient Air Station.

Station Code	Address	Lat / Long	UTM (NAD 83)	Elevation	Intake ht. (above ground)
E206167	Clover Road Pemberton, BC	50° 19' 27" N 122° 47' 19" W	Zone 10 514968 E 5574475 N	200 m	~3.5 m

While data is limited at the Pemberton station, analysis of the diurnal cycles of O_3 in summer reveal that the concentrations are not indicative of a rural, background site, even though that was the intention for this station. A detailed report from a study of O_3 along the Sea-to-Sky corridor (from Horseshoe Bay to Lillooet Lake) will explore these issues in more detail and will be released in 2005.

Table 5.16: Annual Summary of Ozone (O_3) Concentrations Measured in Pemberton from 1985 to 1986.

Year	% Data Capture	Annual Average O_3 Conc. ($\mu g/m^3$)	Max. 1-hour O_3 Conc. ($\mu g/m^3$)	No. of 1-hour Values		Maximum 24-hour O_3 Conc. ($\mu g/m^3$)	No. of 24-hour (discrete daily occurrence) Values	
				> 100 $\mu g/m^3$	> 160 $\mu g/m^3$		> 30 $\mu g/m^3$	> 50 $\mu g/m^3$
1985	74.9	36	150	56	0	99	4012 (167 days)	1314 (54 days)
1986	38.9	n/a	90	n/a	n/a	72	n/a	n/a

Squamish

In July 1995, WLAP commenced ground-level ozone monitoring in Squamish, B.C. Between July 1995 and December 2001, the National 1-hour "Maximum Desirable" and "Maximum Acceptable" Ozone Objectives were exceeded 216 and 6 times, respectively, with exceedances limited to the period of April to September. Details of the 1-hour, 24-hour and annual ozone concentrations for all measured years in Squamish is presented in Table 5.17. All 6 exceedances of the "Maximum Acceptable" Ozone Objective occurred in July 1998 and resulted in the issuance of an air quality advisory which instructed residents with existing respiratory ailments to consider reducing physical exertion and minimizing outdoor activity.

Table 5.17: Annual Summary of Ozone (O_3) Concentrations Measured in Squamish from 1995 to 2001.

Year	% Data Capture	Annual Average O_3 Conc. ($\mu g/m^3$)	Max. 1-hour O_3 Conc. ($\mu g/m^3$)	No. of 1-hour Values		Maximum 24-hour O_3 Conc. ($\mu g/m^3$)	No. of 24-hour (discrete daily occurrence) Values	
				> 100 $\mu g/m^3$	> 160 $\mu g/m^3$		> 30 $\mu g/m^3$	> 50 $\mu g/m^3$
1995	36.0	n/a	112	n/a	n/a	69	n/a	n/a
1996	95.2	30	134	41	0	87	4369 (182 days)	973 (41 days)
1997	95.6	26	154	28	0	73	3141 (130 days)	442 (20 days)
1998	95.4	30	172	67	6	77	4261 (181 days)	728 (26 days)
1999	95.1	28	132	31	0	76	3884 (162 days)	970 (41 days)
2000	91.2	26	144	17	0	72	3231 (139 days)	428 (17 days)
2001	93.8	29	134	23	0	79	3689 (158 days)	760 (32 days)

A graphical depiction of the data in Table 5.17 is provided in Figure 5.10. This figure shows that the Maximum Acceptable Objective for Ozone is exceeded every year. It also shows that there is no discernable trend in the ozone concentrations in the past 6 years. A further analysis of just the 1-hour ozone data is presented in Figure 5.11. This figure shows that the 25th to 75th percentile concentrations remain about the same from year to year, but that the maximum 1-hour concentrations fluctuate. These fluctuations in hourly concentrations tend to be influenced by meteorological conditions rather than changes in emissions. Ozone concentrations in Squamish are similar in magnitude to concentrations in the eastern portion of Greater Vancouver (Pitt Meadows, Abbotsford) but are lower than those in the most-eastern areas of the Fraser Valley such as Chilliwack and Hope where air quality advisories are issued every summer.

The seasonality of ozone concentrations in Squamish can be easily viewed in a 2-dimensional data map showing all hourly concentrations of ozone on a colour scale for a particular year. Figure 5.12 shows the ozone concentrations for the year 1998 (in which the 160 $\mu g/m^3$ objective was exceeded) in Squamish, showing the months of the year on the horizontal x-axis and the time of day on the vertical y-axis. Concentrations are given for each hour and are given in $\mu g/m^3$ (higher concentrations are darker colours).

Figure 5.12 gives an annual overview of the diurnal and seasonal patterns of O_3 concentrations in Squamish. This figure shows a distinct pattern related to solar radiation (hours of sunlight) which can be further related to the temperatures, radiation and daytime vehicle emissions needed to promote the photochemical reactions responsible for producing ground-level ozone. Generally, there appears to be a peak of ozone concentrations in the summer months in the late afternoon, although there are also peaks in the spring. The spring peaks are most likely related to springtime stratospheric intrusion of ozone (these events are quite distinguishable because the concentrations don't decrease significantly at night even though solar radiation is unavailable). Another noticeable pattern is the "zero-ing out" of ozone during the night-time hours in late summer (very light colours in the overnight hours). These light-coloured areas indicate that ozone titration (elimination) is occurring at night, and that the necessary NO_x is available to fuel these chemical reactions. This usually occurs when high pressure systems dominate over the area and prevent the NO_x that has been emitted from mobile sources from dispersing, and thereby fueling ozone production during hot, sunny daytime hours, and fueling ozone destruction at night.

Figure 5.10: 1-hour Maximum, 24-hour Maximum, and Annual Average O_3 concentrations for the years 1996-2001 in Squamish.

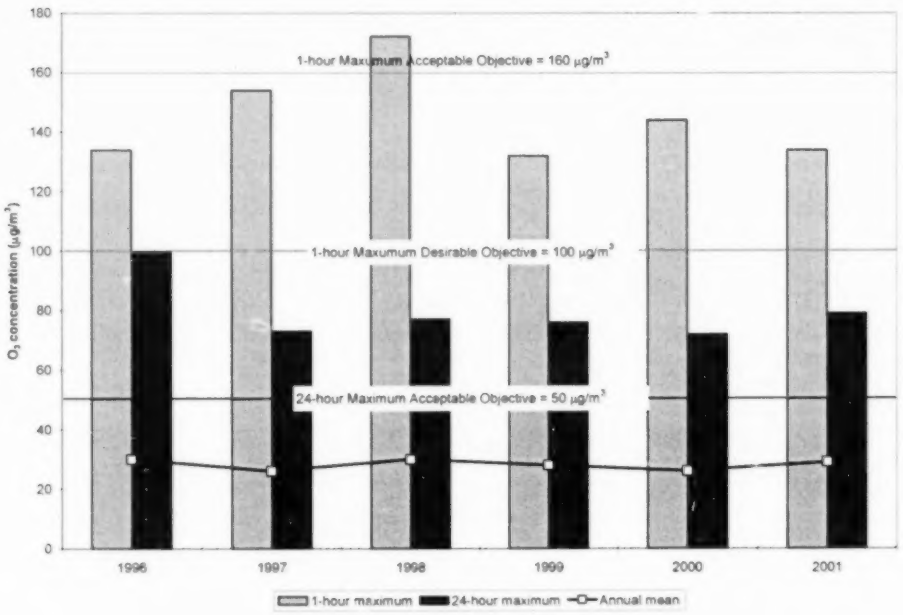


Figure 5.11: 1-hour Maximum (top line), Minimum (bottom line), 25th (bottom of column) and 75th percentile (top of column) O_3 concentrations for the years 1996-2001 in Squamish.

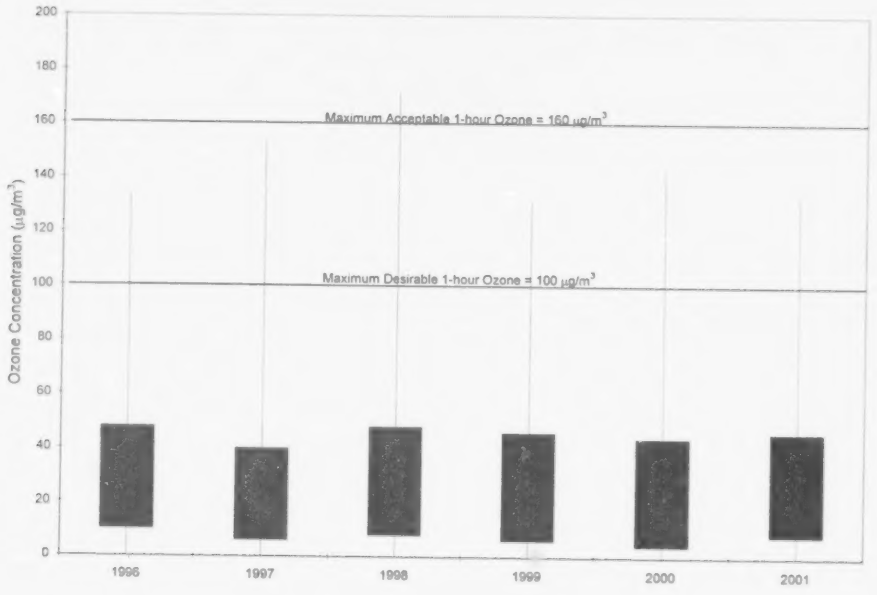
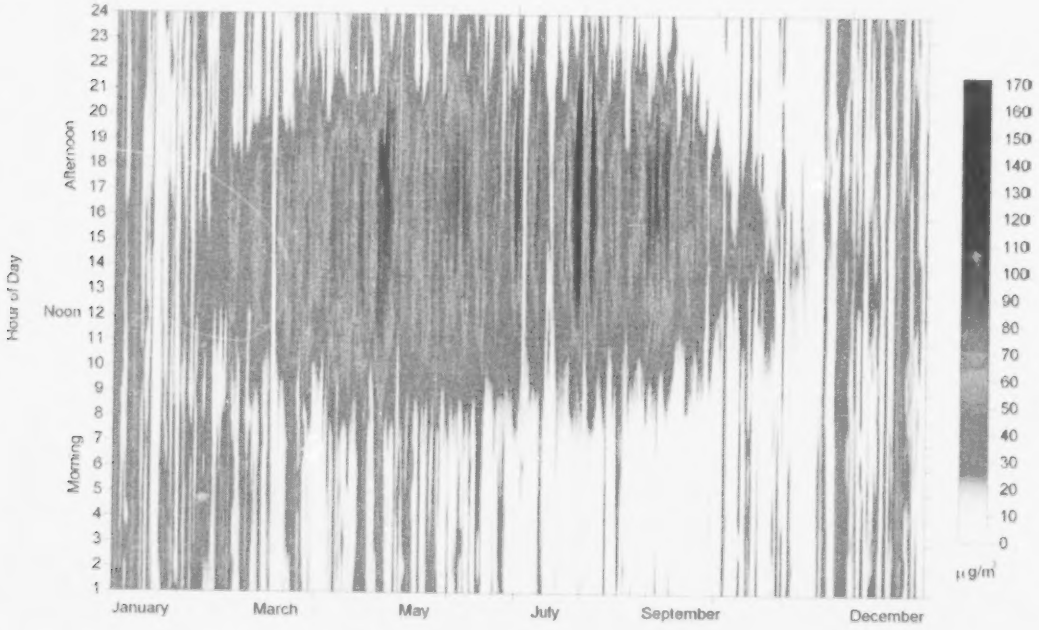


Figure 5.12: Data map of 1-hour ozone concentrations in 1998 for Squamish



Canada-Wide Standards

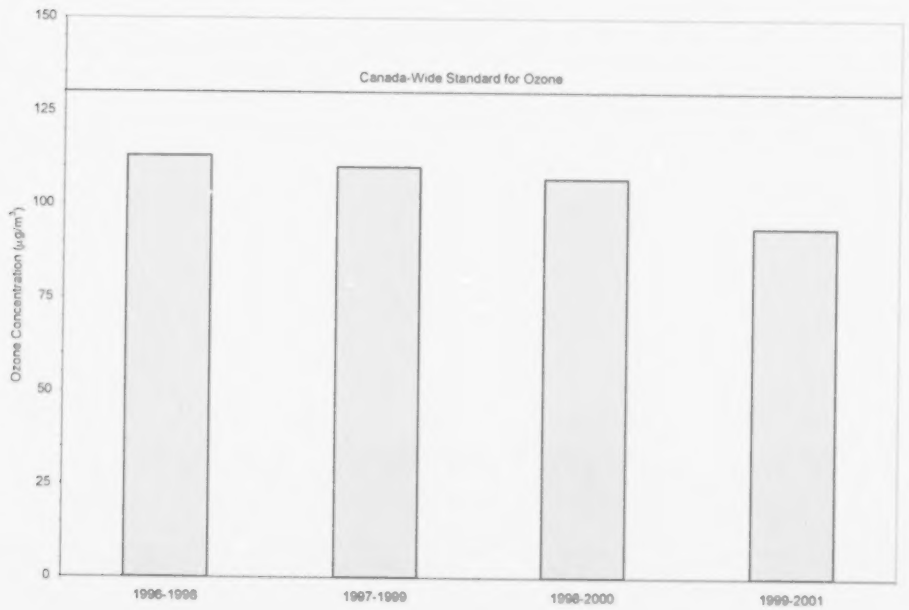
The calculations to compare with the Canada-Wide Standard (CWS) for Ozone were also completed for Squamish. The CWS determination for ozone is 65 ppb or 130 $\mu g/m^3$ based on the annual 4th-highest 8-hour ozone concentration, averaged over 3 years. Table 5.18 shows the 4th highest 8-hour O_3 concentration for each year of measurement, and the subsequent CWS for that year using data from the previous 2 years in the calculation. This table indicates that the high ozone event in 1998 strongly influenced the CWS for the years in which it was included in the calculation, giving the *appearance* of a downward trend in maximum 8-hour ozone concentrations.

Table 5.18: Annual Summary of CWS Ozone (O_3) Concentrations Measured in Squamish from 1996 to 2001.

Year	4th Highest 8-Hour O_3 Concentration ($\mu g/m^3$)	CWS (incl. 2 previous years) ($\mu g/m^3$)
1996	105	n/a
1997	99	n/a
1998	135	113
1999	95	110
2000	90	107
2001	96	94

The apparent decreasing trend is illustrated in Figure 5.13. There is, however, insufficient data to conclude that there is a decreasing ozone trend in Squamish because of the bias from the meteorological conditions and 2-day ozone event in 1998. In fact, preliminary data from 2002 indicates that the CWS value for that year is slightly higher than the 1996 value, and that the resulting CWS determination for 2000-2002 would be higher (against the apparent trend) than that from the 1999-2001 period.

Figure 5.13: Canada-Wide Standard Determination for Ozone for the years 1996-2001 in Squamish. The CWS is given in $\mu g/m^3$ ($130\ \mu g/m^3$ is equivalent to 65 ppb).



Whistler

A TECO Ozone Monitor was installed in Whistler in April 2001 on the roof top of the Meadow Park Sports complex. Details about the station are presented in Table 5.19, and photographs of the station are given in Appendix A. This station was installed to assess whether the concentrations of ozone north of Squamish were similar to those in the Lower Sea-to-Sky Airshed.

Table 5.19: Summary of Station Details for Whistler Ambient Air Station.

Station Code	Address	Lat / Long	UTM (NAD 83)	Elevation (ASL)	Intake ht. (above ground)
E227431	8107 Cameno Dr., Whistler, BC	50° 08' 40" N 122° 57' 38" W	Zone 10 502820 E 5554693 N	640 m	14.8 m

The results from the first 9 months of ozone monitoring in Whistler indicate that the concentrations in this municipality are similar to those measured in Squamish. Table 5.20 lists the annual average and maximum 1-hour and 24-hour O_3 concentrations measured in Whistler in 2001. The maximum 1-hour concentration was 122 $\mu g/m^3$, compared with Squamish's maximum of 134 $\mu g/m^3$ in the same year. However, the 1-hour Maximum Desirable air quality objective for ozone was exceeded 55 times in Whistler, but only 23 times in Squamish. Slightly over half of the 55 hours in which the ozone concentration in Whistler exceeds 100 $\mu g/m^3$ occur in May, when movement of stratospheric ozone down to tropospheric levels most often occurs. Therefore, the higher number of springtime ozone exceedences in Whistler are most likely due to its elevation (600 m above Squamish), and not to any additional emission sources.

Table 5.20: Annual Summary of Ozone (O_3) Concentrations Measured in Whistler in 2001.

Year	% Data Capture	Annual Average O_3 Conc. ($\mu g/m^3$)	Max. 1-hour O_3 Conc. ($\mu g/m^3$)	No. of 1-hour Values		Maximum 24-hour O_3 Conc. ($\mu g/m^3$)	No. of 24-hour (discrete daily occurrence) Values	
				> 100 $\mu g/m^3$	> 160 $\mu g/m^3$		> 30 $\mu g/m^3$	> 50 $\mu g/m^3$
2001	66	36	122	55	0	80	3527 (151 days)	1199 (48 days)

Further investigation into the patterns of ozone concentrations and potential causes for the higher concentrations of ozone in the Sea-to-Sky Airshed were conducted in 2003 and will be presented in a separate report. Please see http://wlapwww.gov.bc.ca/sry/p2/eq/index.html for report updates.

5.5 PM_{10}

5.5.1 Characteristics

Particulate Matter under 10 microns in diameter is also referred to as PM_{10} or as 'inhalable fine particulate'. These particles are small enough to be inhaled and can be deposited in the thoracic region of the lungs[6]. For this reason, they are of significant concern because of their impact on human health, and their abundance in the Sea-to-Sky region from combustion sources such as wood burning, vehicle exhaust, industrial sources as well as dust.

The health effects of PM_{10} (and even smaller $PM_{2.5}$ particles) have received increased attention over the last decade because of a heightened understanding of the health effects associated with PM_{10}. Epidemiological studies have shown a correlation between PM_{10} and daily respiratory and cardiac mortality, increased hospital admissions, increased prevalence of bronchitis and an increased risk of lung cancer[5].

5.5.2 Sources

The primary sources of PM_{10} in the Sea-to-Sky Airshed are from the pulp and paper industry (40% of emissions) as well as mobile sources and road dust, and area sources such as open burning and space heating (33%).

5.5.3 Objectives

There are no national air quality objectives for PM_{10}. The Province of British Columbia has a B.C. Level B Objective of 50 $\mu g/m^3$ for a 24-hour rolling (any 24 consecutive hours, not necessarily from midnight to midnight) average. The Health Reference Level of 25 $\mu g/m^3$ for a 24-hour rolling average is often used as a management standard as well, although it is not recognized officially as an objective by the Province. Studies have shown that there are no levels of inhalable particulate matter below which there are no adverse health effects.

5.5.4 Monitoring Results

PM_{10} is monitored continuously in Squamish and Langdale. Particulate Matter is also measured non-continuously in various areas of the Sea to Sky Airshed, as described in Section 6.0. Details regarding the Squamish Ambient Monitoring station can be found in Table 5.2, and details regarding the Langdale Ambient Monitoring Station can be found in Table 5.4.

Squamish

In Squamish, PM_{10} levels exceeded the 50 $\mu g/m^3$ BC Level B Objective on 6 days in 1995, but they have since remained below this level by just a few (less than 10) $\mu g/m^3$, as seen in Table 5.21. In most cases, the Health Reference Level of 25 $\mu g/m^3$ is exceeded during the summer months coincident with stable and stagnant air masses that remain over the region and inhibit the dispersion of pollutants. On occasion PM_{10} concentrations can rise in winter and are typically associated with outflow winds from the interior of the province or with open burning land clearing events that occur intermittently in the region.

The 24-hour maximum, minimum and 25th and 75th PM_{10} concentrations for the years 1995 through 2001 are shown in Figure 5.14. While there is no apparent trend in the 25th to 75th percentile range, this figure does illustrate that PM_{10} in Squamish, while considered 'good', occasionally exceeds the Health Reference Level, and improvements are still warranted.

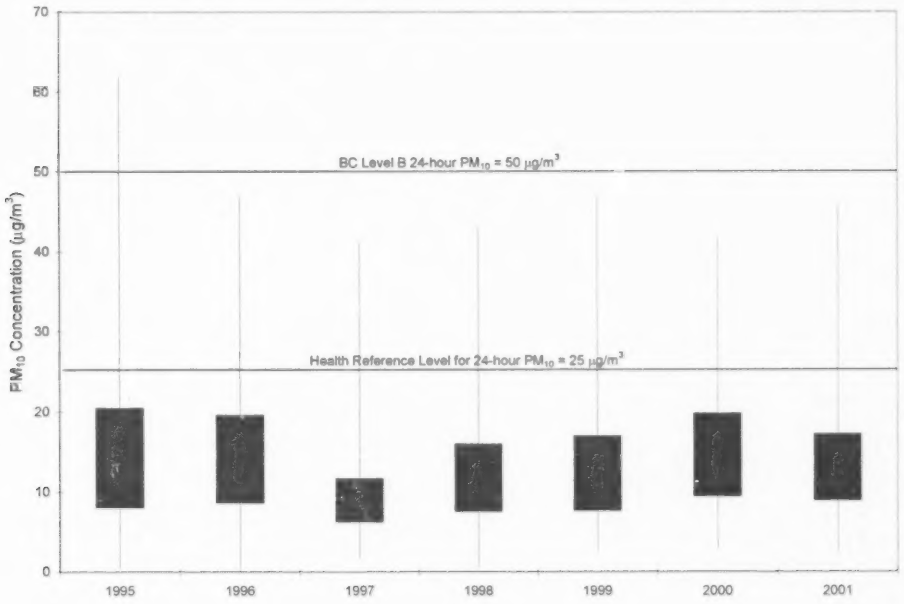
A pollution rose for PM_{10} in Squamish is shown in Figure 5.15. As 24-hour averaged wind values may conceal PM_{10} and wind direction correlations, 1-hour PM_{10} values were used in the rose. The rose in Figure 5.15 uses only those hours where the 1-hour PM_{10} concentration was greater than or equal to 75 $\mu g/m^3$. The rose reveals that the high PM_{10} concentrations predominantly occur when winds are from the southwest, during daytime sea-land breeze. The hours where the pollutants are blowing in from the northwest are all in the evening hours (9pm to midnight) when summertime outflow winds likely carry

pollutants back down the valley and towards Howe Sound. Both the daytime and nighttime hours are included in Figure 5.15.

Table 5.21: Annual Summary of PM_{10} Concentrations Measured in Squamish from 1995 to 2001.

Year	% Data Capture	Annual Average PM_{10} Concentration ($\mu g/m^3$)	Maximum 24-hour PM_{10} Concentration ($\mu g/m^3$)	Number of 24-hour periods (daily occurrence) where > 25 $\mu g/m^3$	Number of 24-hour periods (daily occurrence) where > 50 $\mu g/m^3$
1995	95.7	16	62	1386 (87 days)	87 (6 days)
1996	95.6	15	47	1136 (75 days)	0
1997	93.5	10	41	117 (8 days)	0
1998	97.2	12	43	463 (31 days)	0
1999	96.6	13	47	923 (63 days)	0
2000	93.6	15	42	947 (65 days)	0
2001	96.5	14	46	670 (43 days)	0

Figure 5.14: 24-hour Maximum (top line), Minimum (bottom line), 25th (bottom of column) and 75th percentile (top of column) PM_{10} concentrations for the years 1995-2001 in Squamish.



Another method of viewing the seasonality of the PM_{10} concentrations in Squamish is to plot a 2-dimensional colour data map showing the concentrations of PM_{10} on a colour scale for all hours and all days in a particular year (or conglomeration of years). One such data map is shown in Figure 5.16 for the year 1998 (in which the BC Level B Objective was exceeded) in Squamish, showing the months of the year on the horizontal x-axis and the hours of the day on the vertical y-axis. Concentrations are given for each hour and are given in $\mu g/m^3$ (higher concentrations are shown as darker colours).

Figure 5.16 gives an annual overview of the diurnal and seasonal patterns of PM_{10} concentrations in Squamish. This figure shows a distinct diurnal pattern related to solar radiation (hours of sunlight) which can be further related to both the timing of turbulent mixing in the atmosphere, as well as the time of day when emissions are higher. Generally, there appears to be an initial spike in concentrations in the morning just after sunrise, which is presumably due to pollutants that were trapped overnight in the residual layer (above the stable nocturnal boundary layer) being mixed into the growing surface mixed layer. Typically the concentrations decrease again approximately one hour later, after the residual pollutants have become more dispersed in the growing boundary layer and the sea-land breeze has strengthened. On some days in the late spring and summer, this phenomenon does not occur (i.e. higher concentrations occur steadily throughout all hours of the day), which in most cases is due to strong high pressure systems which dominate over the area and suppress pollutant mixing.

In the afternoon, particularly in summer, there is a peak in PM_{10} concentration coincident with increases in emissions from traffic and both small and large industrial activities. As well, there are strong winds from the south that may transport pollutants from the southern Howe Sound / Georgia Strait and the greater Vancouver area into the region, thereby contributing to a greater concentration of PM_{10} than might be expected from just local emissions. Future dispersion modelling may help in determining how much particulate matter concentrations in Squamish are influenced by local sources vs. distant advected sources.

Overnight in summer, the PM_{10} levels tend not to decrease until well after midnight, and that decrease is often minor. In summer, the strong southern sea-land winds tend to be sustained until late into the evening, with conditions becoming very calm after midnight (see Figure 4.4) contributing to nocturnal inversions.

Figure 5.15: Frequency and Direction of Winds Associated with 1-hour PM_{10} Concentrations Equal to or Higher than 75 $\mu g/m^3$ Measured in Squamish from 1995 to 2001. (The total length of each 'petal' is indicative of the relative frequency of occurrence of winds *from* that direction; for a given wind direction, each colour represents the relative proportion of wind speed ranges).

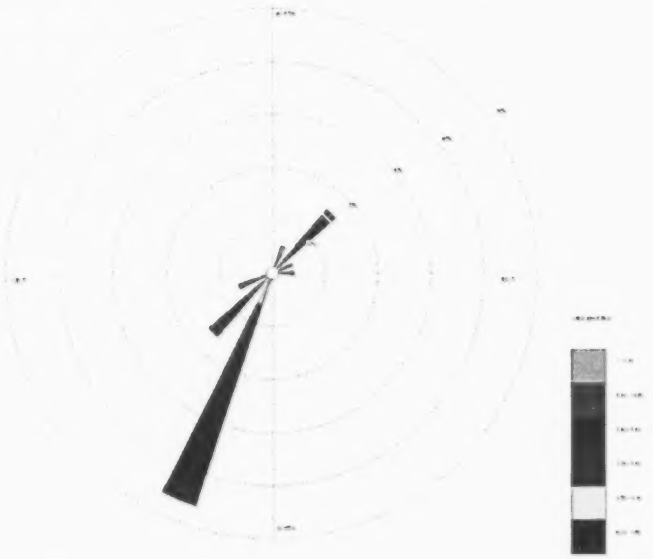
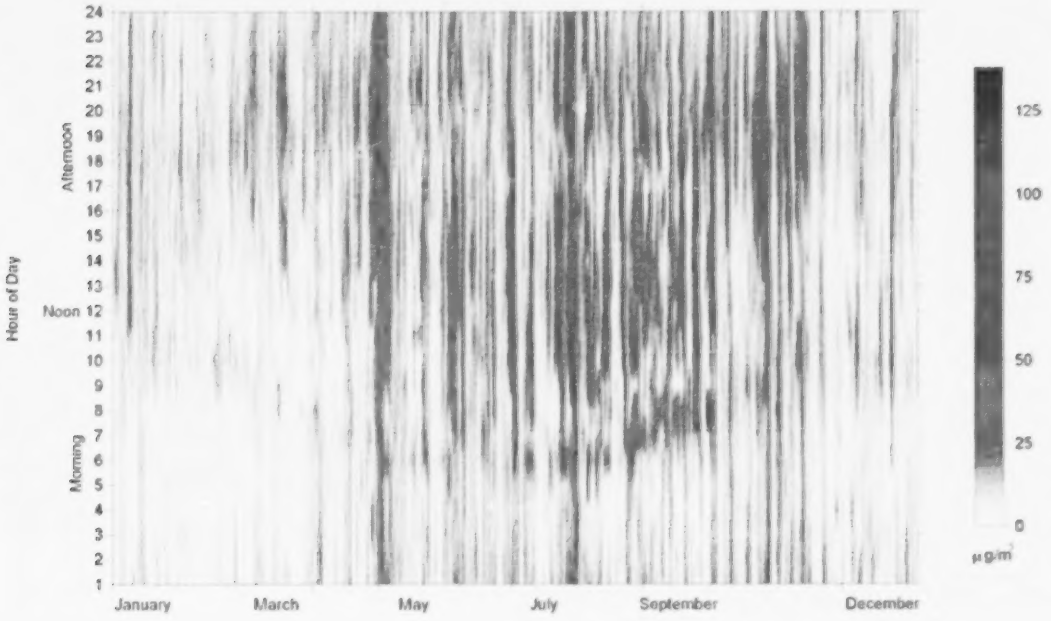


Figure 5.16: Data map showing 1-hour concentrations of PM_{10} for all hours in 1998 in Squamish. Higher concentrations are shown as darker colours.



Langdale

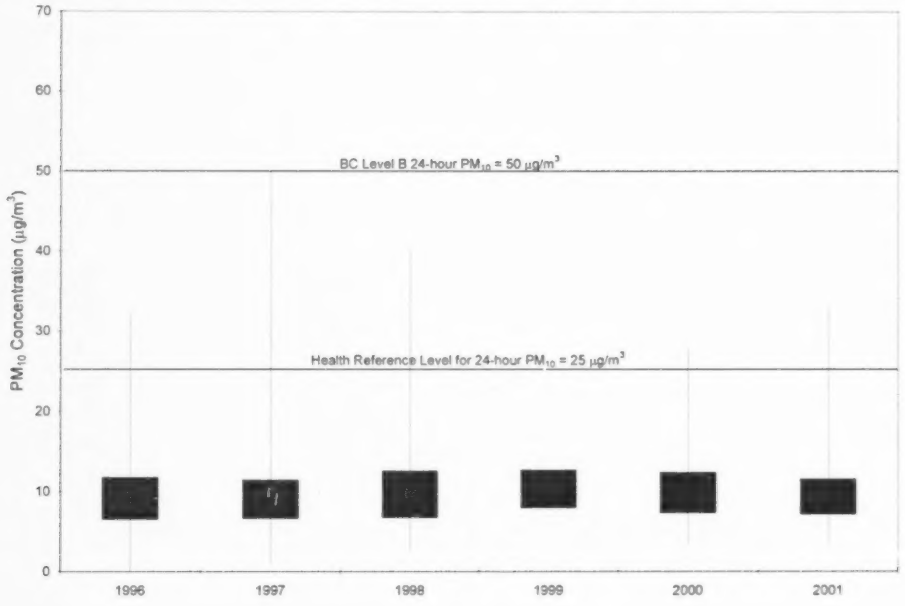
In Langdale, PM_{10} concentrations are considerably lower than those measured in Squamish (the annual average is approximately 5 $\mu g/m^3$ lower). Table 5.22 outlines the annual summary of PM_{10} concentrations measured in Langdale from 1996 to 2001. In Langdale, the maximum 24-hour PM_{10} concentration has reached 50 $\mu g/m^3$ on one occasion in 1997, and 40 $\mu g/m^3$ in 1998, but in other years has remained at least 10 $\mu g/m^3$ lower than the maximum levels in Squamish. There have also been a number of years in Langdale when even the 25 $\mu g/m^3$ Health Reference Level has not been exceeded, indicating that Langdale has some of the lowest measured PM_{10} concentrations in the Lower Mainland.

Table 5.22: Annual Summary of PM_{10} Concentrations Measured in Langdale from 1996 to 2001.

Year	% Data Capture	Annual Average PM_{10} Concentration ($\mu g/m^3$)	Maximum 24-hour PM_{10} Concentration ($\mu g/m^3$)	Number of 24-hour periods where >25 $\mu g/m^3$	Number of 24-hour periods where > 50 mg/m3
1996	98.1	9	32	18 (2 days)	0
1997	99.2	9	50	51 (5 days)	0
1998	49.7	n/a	40	137(5 days)	0
1999	56.8	n/a	24	0	0
2000	96.8	10	28	41 (4 days)	0
2001	97.2	10	33	22 (2 days)	0

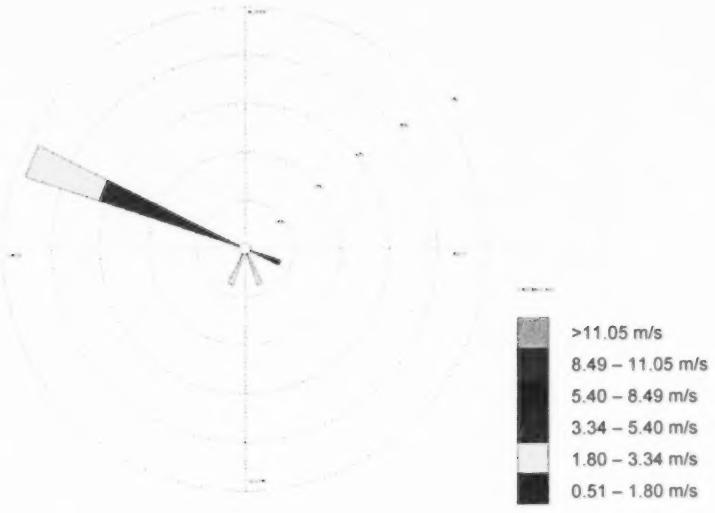
The 24-hour maximum, minimum and 25th and 75th percentile concentrations for PM_{10} in Langdale are illustrated in Figure 5.17. The maximum and minimum values for 1999 are not shown because missing data occurred in the summer months when the highest PM_{10} concentrations are usually measured. In general, the concentrations in Langdale are lower than those in Squamish, and little year-to-year changes were observed in the 25th and 75th percentile concentrations even though there are fluctuations in the minimum and maximum values.

Figure 5.17: 24-hour Maximum (top line), Minimum (bottom line), 25th (bottom of column) and 75th percentile (top of column) PM_{10} concentrations for the years 1996-2001 in Langdale.



A pollution rose for PM_{10} in Langdale is shown in Figure 5.18. As 24-hour averaged wind values may conceal PM_{10} and wind direction correlations, 1-hour PM_{10} values were used in the rose. The rose in Figure 5.18 uses only those hours where the 1-hour PM_{10} concentration was greater than or equal to 75 $\mu g/m^3$, and only for the years 1996 to 1997 (the Langdale meteorological station was shut down in 1998). The rose reveals that the highest PM_{10} concentrations occur when winds are light and from the northwest, and most often occur late in the evening or early morning, consistent with summertime night time outflow winds. There are a few hours where the pollutants are blowing in from the south to southeast, and these are summer daytime winds. While data is very limited, it appears as though night time outflow winds carry higher pollutant concentrations than daytime inflow winds in Langdale. All winds (both daytime and nighttime conditions) are shown in Figure 5.18.

Figure 5.18: Frequency and Direction of Winds Associated with 1-hour PM_{10} Concentrations Equal to or Higher than 75 $\mu g/m^3$ Measured in Langdale from 1996 to 1997. (The total length of each 'petal' is indicative of the relative frequency of occurrence of winds *from* that direction; for a given wind direction, each colour represents the relative proportion of wind speed ranges).



6.0 POLLUTANTS MEASURED BY NON-CONTINUOUS MONITORS

6.1 PM_{10}

6.1.1 Characteristics

The characteristics of PM_{10} and its health effects are outlined in section 5.5.1.

6.1.2 Sources

The sources of PM_{10} in the Sea-to-Sky Airshed are outlined in section 5.5.2.

6.1.3 Air Quality Objectives

The air quality objectives for non-continuous monitoring of PM_{10} are the same as those used for continuous monitoring (as outlined in section 5.5.3). Namely, the 24-hour PM_{10} B.C. Level B Objective of 50 $\mu g/m^3$.

6.1.4 Monitoring Results

PM_{10} is normally measured by non-continuous high volume (HiVol) samplers over a 24-hour period (midnight to midnight) every sixth day, to avoid sampling bias from emissions that may occur on any particular day. This was done in Horseshoe Bay from 1997 to 1998, in Squamish from 1991 to 1994, and for varying periods in Whistler, Gibsons, and the Squamish region.

Horseshoe Bay

A HiVol PM_{10} monitor was mounted on the roof of the Horseshoe Bay (West Vancouver) Firehall from June 1987 to August 1988. Photographs of the site can be found in Appendix A. As the data is non-continuous, both the arithmetic mean and geometric mean (in parenthesis) were calculated for the annual average, as shown in Table 6.1. While these annual mean values can not be directly compared with values from continuous monitors, they nonetheless provide a sense of the ambient concentrations measured at the site. The measured concentrations were reasonably low, with only a small fraction (9 and 14%, compared with an average of ~ 15% for Squamish's continuous monitoring from 1996-2001) exceeding the Health Reference Level of 25 $\mu g/m^3$. The annual mean is similar to, although slightly lower than values measured in Squamish in the early 1990s.

Table 6.1: Annual Summary of Non-Continuous PM_{10} Concentrations Measured in Horseshoe Bay from 1987 to 1988.

Year	# of Samples	Annual Average PM_{10} Concentration ($\mu g/m^3$)	Maximum 24-hour PM_{10} Concentration ($\mu g/m^3$)	Number of 24-hour samples where >25 $\mu g/m^3$	Number of 24-hour samples where > 50 $\mu g/m^3$
1987	22	18 (16)	40	3	0
1988	34	16 (14)	58	3	1

Squamish

A HiVol PM_{10} monitor was installed on the roof of the Squamish Government Building (for station details, see Table 5.2) in 1990. Photographs of the station can be found in Appendix A. Non-continuous PM_{10} data collected in Squamish between 1990 and 1994 are summarized in Table 6.2. As the data is non-continuous, both the arithmetic mean and geometric mean (in parenthesis) were calculated for the annual average. While these annual mean values can not be directly compared with values from continuous monitors, they nonetheless provide a sense of the ambient concentrations measured at the site. In comparison with PM_{10} data collected in the late 1990s, it appears that average annual PM_{10} levels were

similar to concentrations in the early 1990s in Squamish, although maximum concentrations appear to be greater in the early 1990s.

Table 6.2: Annual Summary of Non-Continuous PM_{10} Concentrations Measured in Squamish from 1990 to 1994. Annual mean is calculated as the arithmetic mean, and the geometric annual mean is provided in parentheses.

Year	# of Samples	Annual Average PM_{10} Concentration ($\mu g/m^3$)	Maximum 24-hour PM_{10} Concentration ($\mu g/m^3$)	Number of 24-hour samples where >25 $\mu g/m^3$	Number of 24-hour samples where > 50 $\mu g/m^3$
1990	1	n/a	17	n/a	n/a
1991	44	21 (18)	51	15	1
1992	42	20 (16)	78	8	2
1993	44	22 (19)	43	12	0
1994	41	18 (16)	32	5	0

Whistler

A PM_{10} Hivol monitor was installed at two different locations in Whistler for two separate PM_{10} monitoring studies conducted in the mid- and late-1990s. The first study (Nov. 1994 to Feb. 1995) was conducted on the roof of the Municipal Hall in Whistler, and is outlined in the report "The Resort Municipality of Whistler Inhalable Particulate (PM_{10}) Study 1994/95" (not currently available on-line). Annual summaries of the data from this study are presented in the upper portion of Table 6.3. Photographs of this site can be found in Appendix A.

The second study (1997 to 2001) was conducted on the roof of the Meadow Park Sports Complex, the site of the present-day Whistler Ambient Air Monitoring Station. Detailed analysis of the results of the PM_{10} study conducted in Whistler can be found in the report entitled "Ambient Air Quality Monitoring Report, Whistler British Columbia, PM_{10} and Ozone, 1997-2001" (http://wlapwww.gov.bc.ca/sry/p2/air_quality/whistler_report.html). On an annual average basis, PM_{10} concentrations in Whistler are lower than those found in Squamish, although maximum values are similar in both communities. Annual summaries of this data can be found in the lower portion of Table 6.3. As the data is non-continuous, both the arithmetic mean and geometric mean (in parenthesis) were calculated for the annual average, as shown in Table 6.3. While these annual mean values can not be directly compared with values from continuous monitors, they nonetheless provide a sense of the ambient concentrations measured at the site.

Table 6.3: Annual Summary of Non-Continuous PM_{10} Concentrations Measured in Whistler from 1994 to 1995 (Municipal Hall) and 1997 to 2001 (Meadow Park).

Year	# of Samples	Annual Average PM_{10} Concentration ($\mu g/m^3$)	Maximum 24-hour PM_{10} Concentration ($\mu g/m^3$)	Number of 24-hour samples where >25 $\mu g/m^3$	Number of 24-hour samples where > 50 $\mu g/m^3$
1994	10	n/a	19	n/a	n/a
1995	4	n/a	22	n/a	n/a
1997	18	n/a	21	n/a	n/a
1998	6	n/a	21	n/a	n/a
1999	40	16 (9)	54	8	1
2000	53	10 (8)	39	3	0
2001	22	n/a	22	n/a	n/a

Gibsons

PM_{10} concentrations were measured at Gibsons Municipal Hall using a non-continuous HiVol sampler between February 1993 and June 1994. The monitor was then moved to Gibsons Fire Hall for 1995. These concentrations are similar to, although slightly lower than measurements taken during the same

period in Squamish. There were no measurement periods in which the BC Level B objective (50 $\mu g/m^3$) for PM_{10} was exceeded.

Table 6.4: Annual Summary of Non-Continuous PM_{10} Concentrations Measured in Gibsons from 1993 to 1995.

Year	# of Samples	Annual Average PM_{10} Concentration ($\mu g/m^3$)	Maximum 24-hour PM_{10} Concentration ($\mu g/m^3$)	Number of 24-hour samples where >25 $\mu g/m^3$	Number of 24-hour samples where > 50 $\mu g/m^3$
1993	39	19	43	9	0
1994	29	n/a	25	0	0
1995	52	13	29	2	0

Squamish Region

PM_{10} was measured in Squamish at three different locations (Garibaldi Highlands Elementary School, Rayburn Road, in Brackendale at the Elementary School, and on Westway Ave in Valleycliffe) from January to March in 1997 for a woodsmoke study. The results of the PM_{10} study are presented in Table 6.5, and show that all measured concentrations were below the BC Level B Objective for PM_{10}, although almost half of the samples in Garibaldi equaled the Health Reference Level of 25 $\mu g/m^3$. This study was conducted during a winter period to assess whether woodsmoke was of concern in the region. It appears that the Garibaldi site did capture local woodsmoke effects and that these effects were near the health reference level. A particulate matter monitor was permanently installed at the Garibaldi location in 2002 to further investigate this phenomenon, although data to date does not reflect the levels captured in 1997 (today they are much lower). A full account of the monitoring data post-2001 will be updated in annual Sea to Sky airshed reports.

Table 6.5: Annual Summary of Non-Continuous PM_{10} Concentrations Measured in Squamish Region from January to March 1997.

Station	# of Samples	Maximum 24-hour PM_{10} Concentration ($\mu g/m^3$)	Number of 24-hour samples where >25 $\mu g/m^3$	Number of 24-hour samples where > 50 $\mu g/m^3$
Garibaldi	23	25	0	0
Brackendale	14	16	0	0
Valleycliffe	11	14	0	0

6.2 $PM_{2.5}$

6.2.1 Characteristics

$PM_{2.5}$ refers to particulate matter under 2.5 microns in diameter, and is also known as "respirable" particulate. Due to the small size of these particles, their potential to penetrate further into the lung where there are no cilia is greater than that for larger (ie PM_{10}) particles. Health effects of $PM_{2.5}$ are similar to those of PM_{10} (although there is a stronger linkage found between $PM_{2.5}$ and health effects), including decreased lung function, increases in mortality and hospitalization due to cardiorespiratory diseases, and increases in heart rate and blood pressure[6].

$PM_{2.5}$ also contributes to degraded visibility because these particles are of similar diameter to the wavelength of visible light and are therefore efficient at scattering light. This effect can cause a white-ish haze that is commonly seen in summer during stagnant meteorological conditions where dispersion of pollutants is inhibited.

6.2.2 Sources

Sources of $PM_{2.5}$ in the Sea-to-Sky Airshed are similar to the sources for PM_{10}. However, $PM_{2.5}$ may also form as a secondary particulate through the reaction of certain constituents such as NO_x and ammonia. Two of the most common secondary fine particulates are ammonium nitrate and ammonium sulphate. Ammonia sources were not included in the 1995 Sea-to-Sky Emissions Inventory.

6.2.3 Air Quality Objectives

There are no sub-annual standards for $PM_{2.5}$ which could be used for airshed management purposes. In general, the Health Reference Level of 15 $\mu g/m^3$ for a 24-hour period is sometimes used as a long-term planning target. The Canada Wide Standard for $PM_{2.5}$ (30 $\mu g/m^3$, based on the 98th percentile 24-hour average ambient measurement annually, averaged over 3 consecutive years – see section 3.1) will be applicable in the Sea-to-Sky Airshed after 2004, when 3 consecutive years of data will be available.

6.2.4 Monitoring Results

A non-continuous Rupprecht & Pataschnick Partisol Model 2000 air sampler was installed at the Squamish Ambient Air Monitoring Station in February 2001. For details on the Squamish station, see Table 5.2. The results from the first 11 months of monitoring are shown in Table 6.6. These results are consistent with the seasonal patterns in the PM_{10} data, whereby the highest concentrations are measured in summer when stable and stagnant air masses prevent dispersion of pollutants. In 2001, the Health Reference Level of 15 $\mu g/m^3$ was exceeded on only one occasion (the maximum was 19 $\mu g/m^3$) during the month of August. During that same month, the PM_{10} Health Reference Level of 25 $\mu g/m^3$ was exceeded for 5 days, although the concentrations were never above 40 $\mu g/m^3$.

Table 6.6: Annual Summary of Non-Continuous $PM_{2.5}$ Concentrations Measured in Squamish from February to December 2001.

Month	No. of samples	Maximum 24-hour PM2.5 Concentration ($\mu g/m^3$)	Number of 24-hour samples where > 15 $\mu g/m^3$
February 2001	1	12	0
March 2001	5	8	0
April 2001	5	8	0
May 2001	5	9	0
June 2001	6	8	0
July 2001	6	10	0
August 2001	5	19	1
September 2001	5	12	0
October 2001	6	10	0
November 2001	5	11	0
December 2001	5	13	0

6.3 TSP

6.3.1 Characteristics

Total suspended particulate (TSP) is a general term for particulate matter ranging in diameter from 0.1 to 40 micrometres. These airborne particles can also be referred to as dust, smoke, ash or pollen. In general the health effects tend to be associated with those particles that are smallest in diameter and can penetrate deep into the lungs (see $PM_{2.5}$ and PM_{10}), while the larger particles tend to be a nuisance and may cause mild irritation or aesthetic issues from deposition. The seriousness of the health effects from all particulates is also dependent on the chemical characteristics of the particle, and may be of greatest detriment when associated with toxic components.

6.3.2 Sources

The major sources of total suspended particulate in the Sea-to-Sky Airshed are industrial sources, fuel burning for space heating, and road dust. For sources of the finer fraction particulates, see the previous sections on PM_{10} and $PM_{2.5}$.

6.3.3 Ambient Criteria

The BC provincial air quality objectives for total suspended particulate (TSP) in British Columbia are based on a 24 hour and annual (geometric mean) averaging period and are presented in Table 6.7. The provincial guidelines are given for both averaging periods for all levels, while the national standard is more stringent for the 24-hour averaging period for the Maximum Acceptable Level only. For an explanation of the BC and Federal objectives and their definitions, see section 3.0.

Table 6.7: Provincial and National Air Quality Objectives for Total Suspended Particulate (TSP).

Pollutant	Averaging Period	BC Level A ($\mu g/m^3$)	BC Level B ($\mu g/m^3$)	BC Level C ($\mu g/m^3$)	Maximum Desirable ($\mu g/m^3$)	Maximum Acceptable ($\mu g/m^3$)	Maximum Tolerable ($\mu g/m^3$)
TSP	24 hour	150	200	260		120	400
	Annual (geometric)	60	70	75	60	70	

6.3.4 Monitoring Results

Total suspended particulate was the first class of particulates to be monitored in the Sea-to-Sky Airshed when the monitoring program began. High volume (HiVol) TSP samplers were often co-located with Total Reduced Sulphur monitors to evaluate emissions from industrial sources such as pulp mills. Monitoring was conducted on the roof of the Squamish Government building from 1985 to 1992, at Horseshoe Bay in 1985 and again in 1987, and in Langdale at the YMCA Camp Elphinstone in 1987. Photographs of these stations can be found in Appendix A.

Squamish

TSP concentrations in Squamish were measured from 1985-1992. A summary of the data collected is shown in Table 6.8. Note that the annual mean in this table is the geometric, rather than the arithmetic. What is most notable about these concentrations is the significant decrease in maximum 24-hour and annual concentrations in the late-1980s. This decrease appears to be consistent with decreases in Total Reduced Sulphur concentrations, and is most likely attributable to changes in pollution control technology at the nearby pulp mill at Woodfibre. During the measurement period, the national Maximum Acceptable 24-hour objective of 120 $\mu g/m^3$ was exceeded on 5 occasions over 3 years in the mid-1980s, but was not exceeded again after 1987.

Table 6.8: Annual Summary of Non-Continuous TSP Concentrations Measured in Squamish from 1985 to 1992. Annual mean is calculated as the geometric mean.

Year	# of Samples	Annual Average TSP Concentration ($\mu g/m^3$)	Maximum 24-hour TSP Concentration ($\mu g/m^3$)	Number of 24-hour samples where > 120 $\mu g/m^3$
1985	56	51	172	2
1986	45	34	141	2
1987	44	43	149	1
1988	46	30	88	0
1989	42	28	98	0
1990	43	32	95	0
1991	37	23	100	0
1992	39	24	71	0

Langdale

Total suspended particulate was measured for a brief period in 1987 at the Langdale YMCA Camp Elphinstone, presumably to assess emissions associated with the nearby pulp mill in Port Mellon. A summary of the results is presented in Table 6.9. This brief measurement period showed no samples in exceedance of the 24-hour national maximum acceptable standard of 120 $\mu g/m^3$. These levels are considerably lower than TSP concentrations measured during the same period in Squamish.

Table 6.9: Annual Summary of Non-Continuous TSP Concentrations Measured in Langdale in 1987. Data is insufficient to calculate an annual mean.

Year	# of Samples	Annual Average TSP Concentration ($\mu g/m^3$)	Maximum 24-hour TSP Concentration ($\mu g/m^3$)	Number of 24-hour samples where > 120 $\mu g/m^3$
1987	6	n/a	74	0

Horseshoe Bay

A TSP sampler was placed at the West Vancouver Firehall in Horseshoe Bay for two separate measurement periods – in 1985 and in 1987. While insufficient data was collected to evaluate an annual geometric mean, the 24-hour data reveals that TSP levels were below the strictest 24-hour objectives, and that the maximum concentrations were less than those measured in Squamish during that period, and more similar to concentrations found in Langdale, also at the southern end of Howe Sound. A summary of the data is presented in Table 6.10.

Table 6.10: Annual Summary of Non-Continuous TSP Concentrations Measured in Horseshoe Bay in 1985 and 1987. Data is insufficient to calculate an annual mean.

Year	# of Samples	Annual Average TSP Concentration ($\mu g/m^3$)	Maximum 24-hour TSP Concentration ($\mu g/m^3$)	Number of 24-hour samples where > 120 $\mu g/m^3$
1985	28	n/a	83	0
1987	5	n/a	21	0

7.0 REFERENCES

1. Canadian Council of Ministers of the Environment (CCME). 2002. Guidance Document on Achievement Determination. Canada-Wide Standards for Particulate Matter and Ozone. CCME. ISBN: 1-896997-41-4.

2. Canadian Environmental Protection Act (CEPA) Federal-Provincial Advisory Committee (FPAC). 1998. National Ambient Air Quality Objectives for Particulate Matter. Part 1: Science Assessment Document. Health Canada/Environment Canada.

3. Canadian Environmental Protection Act (CEPA) Federal-Provincial Advisory Committee (FPAC). 1999. National Ambient Air Quality Objectives for Ground-Level Ozone. Summary Science Assessment Document. Health Canada/Environment Canada.

4. Lange, O.S. 1998. The Wind Came All Ways: A quest to understand the winds, waves and weather in the Georgia Basin. Environment Canada, Vancouver B.C. 123 pp.

5. SO2 http://www.atsdr.cdc.gov/toxprofiles/tp116.html

6. Bates, D.V. and R.B. Caton (Ed.), 2002. A Citizen's Guide to Air Pollution. 2nd Ed. David Suzuki Foundation. Vancouver, B.C. 452 pp.

8.0 GLOSSARY

Acid rain or precipitation – precipitation containing harmful amounts of nitric and sulfuric acids formed primarily by nitrogen oxides and sulfur oxides released into the atmosphere when fossil fuels are burned. It can be wet precipitation (rain, snow, or fog) or dry precipitation (absorbed gaseous and particulate matter, aerosol particles or dust). Acid rain has a pH below 5.6. Normal rain has a pH of about 5.6, which is slightly acidic.

Area Sources – Relatively small dispersed sources of emissions such as gasoline stations, residential heating, open burning, and natural emissions.

CCME – Canadian Council of the Ministers of the Environment

Coefficient of Haze - A measurement of visibility interference in the atmosphere.

Criteria Air Contaminants or Common Air Contaminants (CACs) – air contaminants which are commonly measured in urban environments and for which there are usually national or regional standards or objectives. There are typically five CACs – carbon monoxide (CO), nitrogen dioxide (NO_2), particulate matter (PM_{10} or $PM_{2.5}$), sulphur dioxide (SO_2), and volatile organic compounds (VOCs). Because NO_x and VOCs are precursors for ozone (O_3) formation, ozone is sometimes also refereed to as a common air contaminant.

CWS – Canada-Wide Standard

Dustfall – larger solid and liquid particles collected via gravitational settling in an open-mouth container for a designated period of time.

Inhalable Particulate – fine particulate matter with particle diameter of 10 microns or less (see PM_{10})

LSTS – Lower (Squamish and Howe Sound) Sea-to-Sky Airshed

Mobile Sources – on and off road motor vehicles, trains, marine vessels and aircraft.

Nephelometer - an instrument used to measure the light scattering component of light extinction (for the purposes of measuring cloudiness or haziness).

NO_x – nitrogen oxides (comprised of nitrogen oxide and nitrogen dioxide)

NO_2 – nitrogen dioxide

Ozone (Ground Level Ozone – O_3) – a respiratory irritant formed through complex photochemical reactions of precursor contaminants, primarily nitrogen oxides and volatile organic compounds, in the presence of sunlight

PM_{10} – Particulate matter with particle diameter of 10 microns or less

$PM_{2.5}$ – Particulate matter with particle diameter of 2.5 microns or less

Point Sources – Stationary commercial and industrial sources operating under a permit.

Precursor - a substance from which another substance is formed (by a chemical reaction)

SO_2 – sulphur dioxide

STS Airshed – Sea-to-Sky Airshed

Sulfation Plate – a method of monitoring SO_2 over a multi-day averaging period with regard to the atmospheric corrosion of stationary structures or materials.

TRS – Total Reduced Sulphur, refers to a group of sulphurous compounds, made up primarily of dimethyl disulphide (DMDS), dimethyl sulphide (DMS), methyl mercaptan (MESH), and hydrogen sulphide (H_2S).

TSP – total suspended particulates (includes all atmospheric particle sizes)

µg – microgram, 1/1000 of a milligram

USTS – Upper (Whistler and Pemberton) Sea-to-Sky Airshed

UTM – Universal transverse mercator

VOCs – volatile organic compounds

Appendix A

Meteorological Stations

Figure A1. Squamish Meteorological Station tower in 1988 (view looking northeast). Ambient air equipment on rooftop is pictured in foreground of meteorological station.

Figure A2. Squamish Meteorological Station tower in 2003 (view looking southeast). Tower was moved approximately 50 m east of its original location in Figure A1.

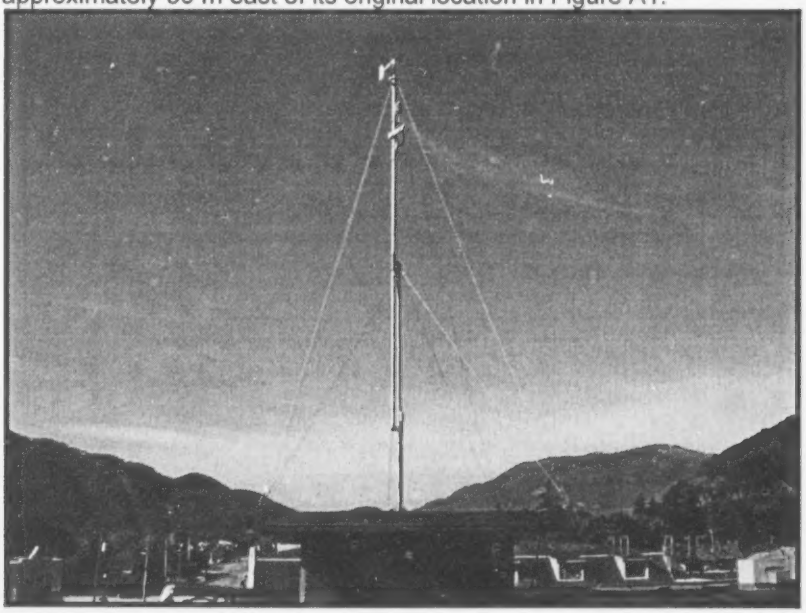
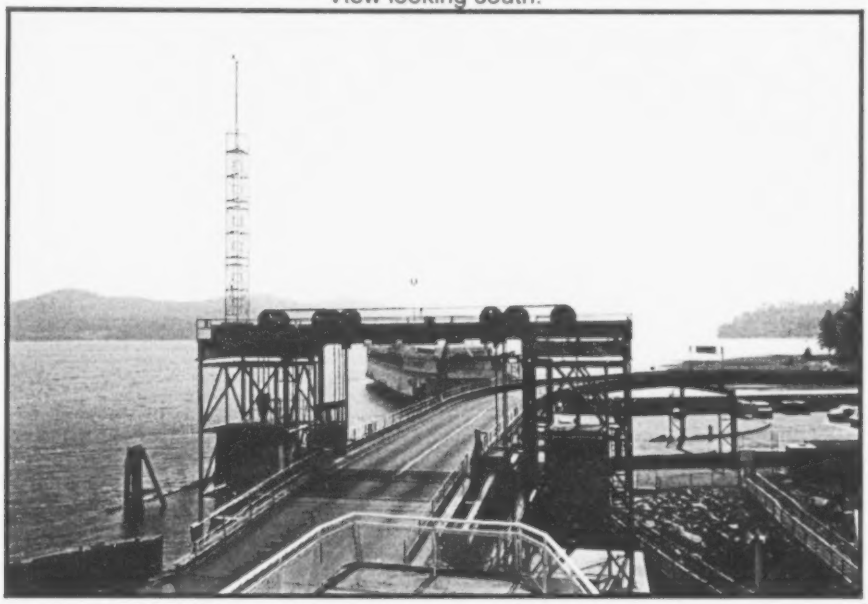


Figure A3. Langdale Meteorological Station tower located at BC Ferries Langdale terminal. View looking south.



There are no historical photos of Horseshoe Bay Meteorological Station (Water Tower on Copper Cliff Rd) available.

Figure A4. Port Mellon (Howe Sound Pulp and Paper) Meteorological Station. The photograph on the left depicts the individual tower on top of a crane in the woodchip sort area (anemometer tower at very top of crane). The photograph on the right is a view looking south from the mill with an arrow indicating the location of the meteorological station tower.

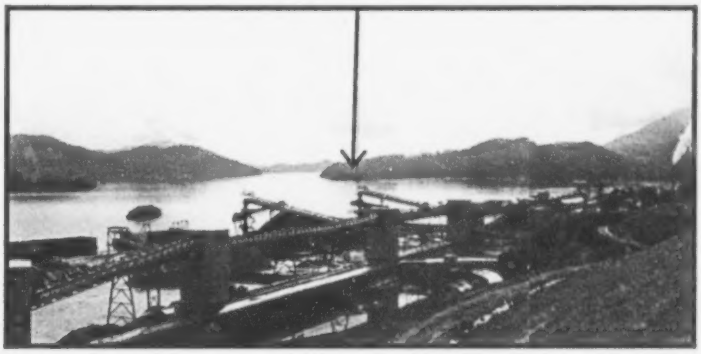
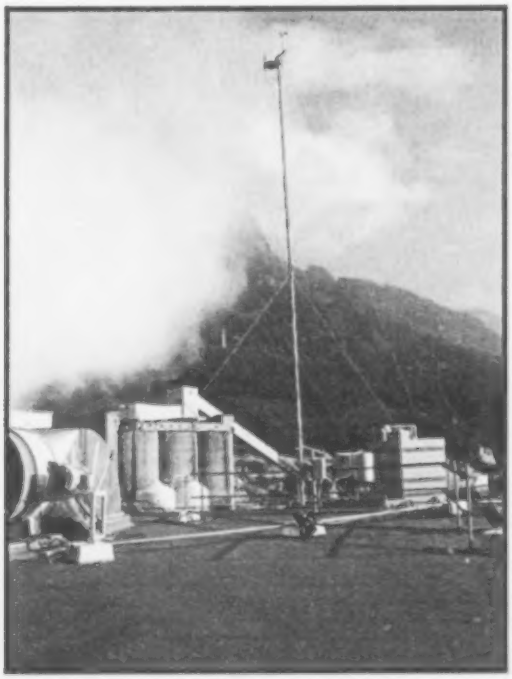


Figure A5. Squamish Western Pulp (Woodfibre) Meteorological Station. This station is non-standard and is meant for dispersion modelling purposes only. The photograph faces north.



Ambient Air Stations

Figure A6. Squamish Ambient Air Monitoring Station. The photograph on the left depicts the station (view looking east) in 1988 with an acid precipitation monitor on the left, total reduced sulphur intakes in the middle, and a total suspended particulate monitor on the right. The photograph on the right depicts the station (view looking southeast) in 2003 with a PM_{10} intake on the left, an air intake for ozone, total reduced sulphur, and sulphur dioxide in centre-left, and a $PM_{2.5}$ sampler on the right.

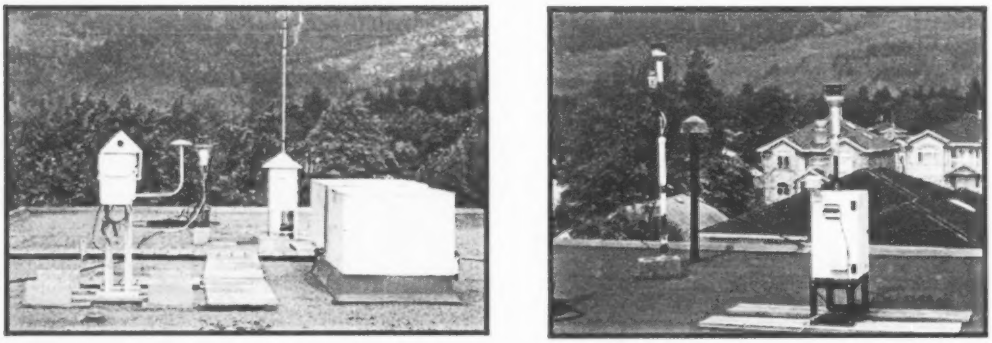


Figure A7. Langdale Ambient Air Monitoring Station. This station is located on the grounds of Langdale Elementary School and includes intakes for PM_{10} on the left and a general intake for analyzing oxides of nitrogen, sulphur dioxide and total reduced sulphur on the right (cone).

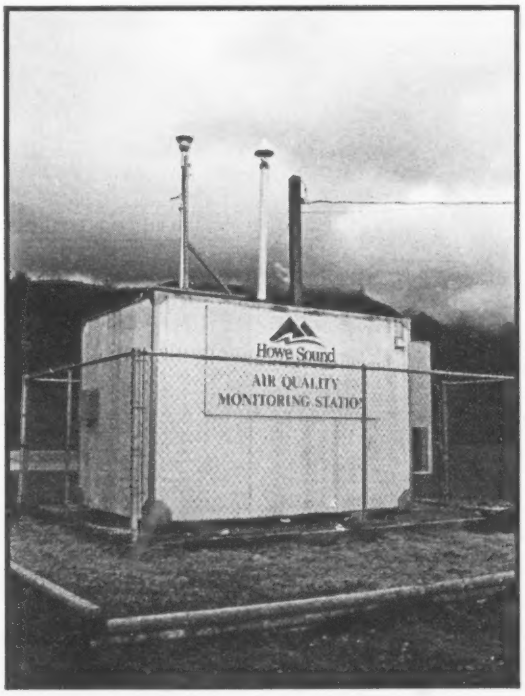


Figure A8. Gibsons Townhall Ambient Air Monitoring Station. Photograph depicts particulate sampler with two intakes attached on the right side for total reduced sulphur and sulphur dioxide monitoring.

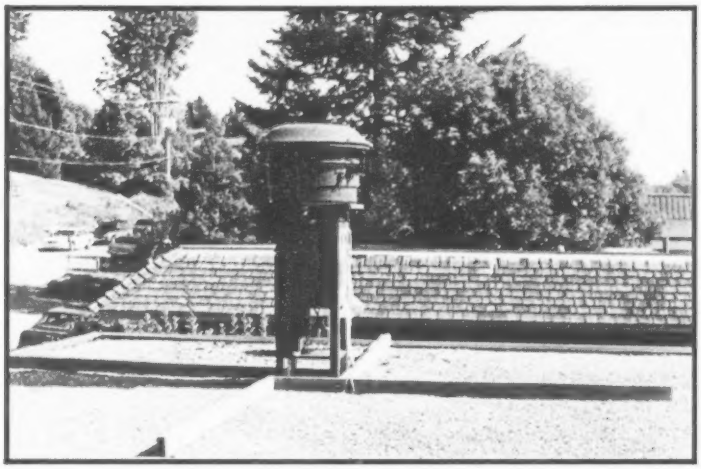


Figure A9. Horseshoe Bay – West Vancouver Firehall Ambient Air Monitoring Station. Photograph depicts the West Vancouver Fire Department No. 2 Station with a total suspended particulate monitor mounted on the centre of the garage rooftop.

There are no historical photos of Horseshoe Bay Madrona Ambient Air Monitoring Station available.

There are no historical photos of Horseshoe Bay Libby Lodge Ambient Air Monitoring Station available.

There are no historical photos of Horseshoe Bay Ferry Terminal Ambient Air Monitoring Station (1988) available.

There are no historical photos of Porteau Cove Ambient Air Monitoring Station (1988) available.

Figure A10. Horseshoe Bay - 6929 Isleview Dr. Ambient Air Monitoring Station. The photograph on the left depicts the total reduced sulphur intake hanging from the balcony at the residence, and the photograph on the right shows the view of that balcony from the shoreline.

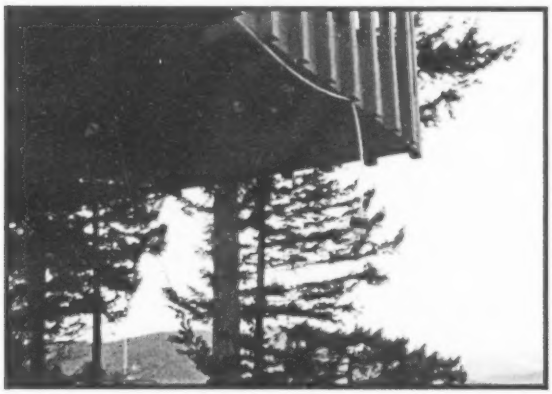


Figure A11. Langdale YMCA Camp Elphinstone Ambient Air Monitoring Station. The photograph depicts the total suspended particulate monitor (large brown unit) and the intake line beside it for the total reduced sulphur monitor.

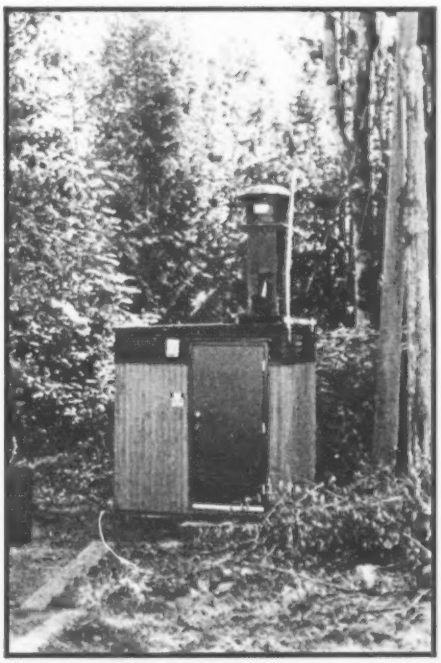


Figure A12. Gibsons Firehall Ambient Air Monitoring Station. The photograph depicts the PM_{10} monitor above the garage of the firehall. The intake for the total reduced sulphur monitor was located just below the PM_{10} monitor but is not visible in this photograph.

There are no historical photos of Gambier Island Ambient Air Monitoring Station available.

Figure A13. Whistler Townhall Ambient Air Monitoring Station. This photograph depicts a PM_{10} monitor on the roof of the Resort Municipality of Whistler's municipal hall.

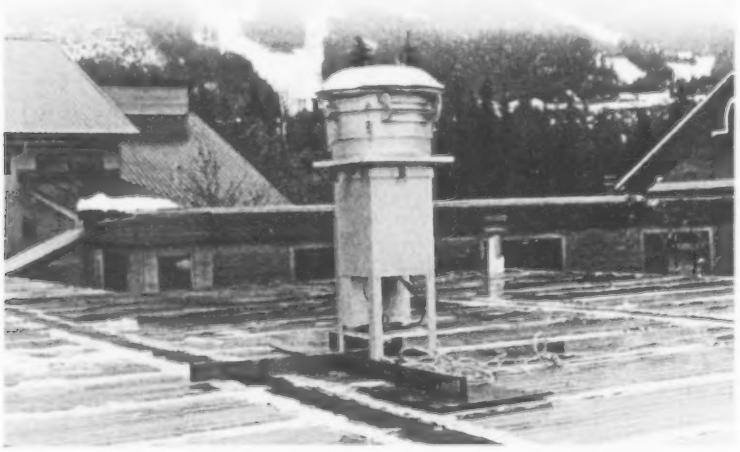


Figure A14. Whistler Meadow Park Ambient Air Monitoring Station. The photograph depicts a PM_{10} monitor looking east on the roof of the Meadow Park Sports Complex. The intakes for ozone and oxides of nitrogen are approximately 25 m to the west of this PM_{10} monitor.

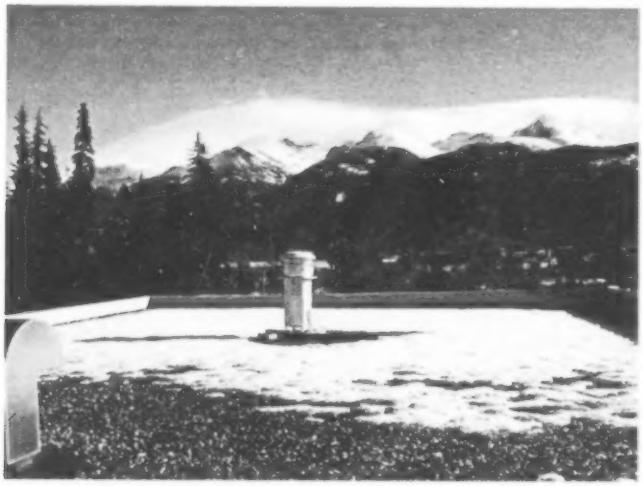
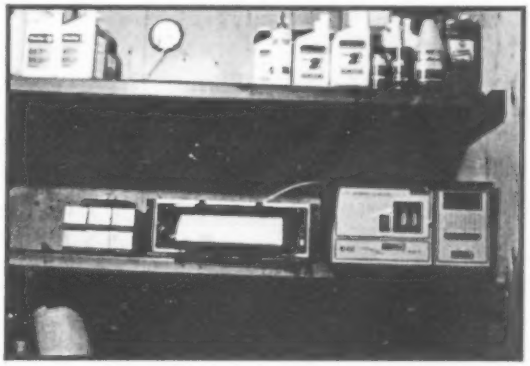


Figure A15. Pemberton – Clover Road Ambient Air Monitoring Station. The photograph on the right depicts the home in which the monitor was placed (inside garage where van is parked) looking southeast in 1984. The photograph on the right depicts the interior shelf in the garage where the ozone monitor was mounted.



APPENDIX B – Squamish Wind Roses

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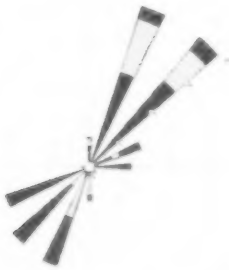

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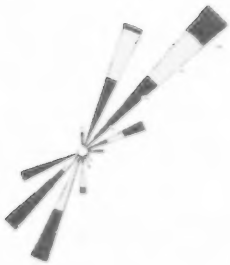

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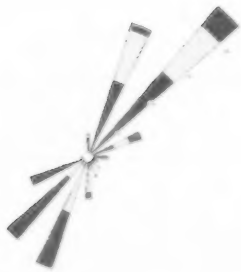

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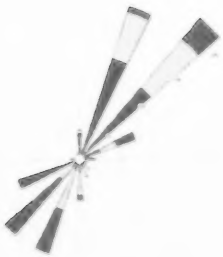

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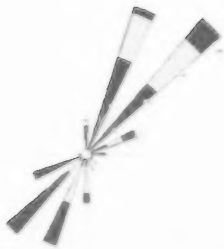

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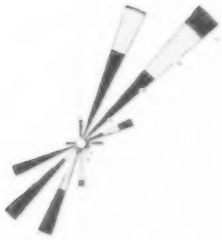

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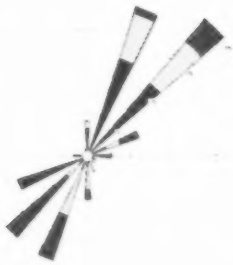

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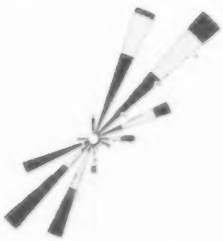

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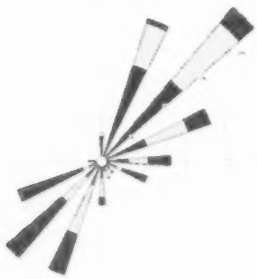

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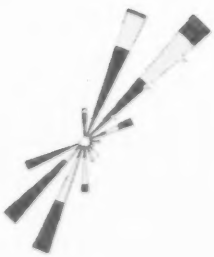

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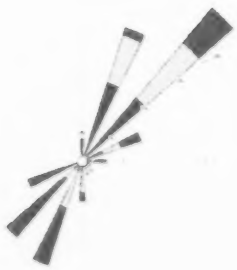

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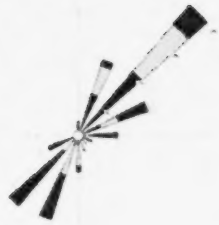

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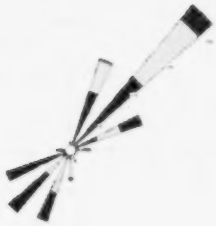

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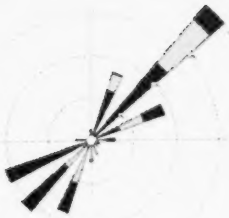

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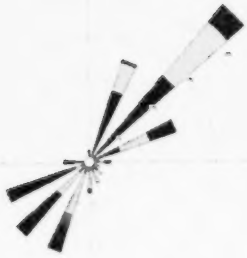

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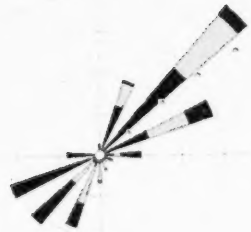
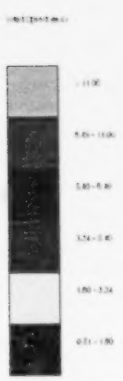


2001

APPENDIX C – Langdale Wind Roses



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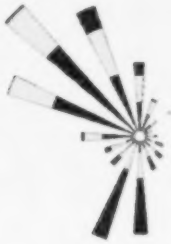

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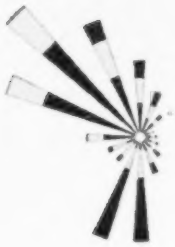

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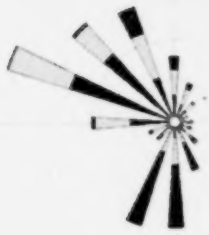
1992

1993

1994



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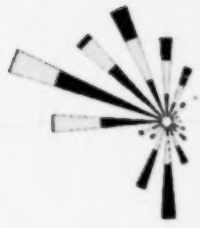

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